ASEAN GUIDELINES ON SOIL AND NUTRIENT MANAGEMENT

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DEUTSCHE ZUSAMMENARBEIT

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ASEAN SUSTAINABLE AGRIFOOD SYSTEMS

ASEAN GUIDELINES ON SOIL AND NUTRIENT MANAGEMENT

The Regional Soil and Nutrient Management Expert Group

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Under the purview of the ASEAN Sectoral Working Group on Crops (ASWGC)

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EXECUTIVE SUMMARY

Purpose and scope of the Guidelines

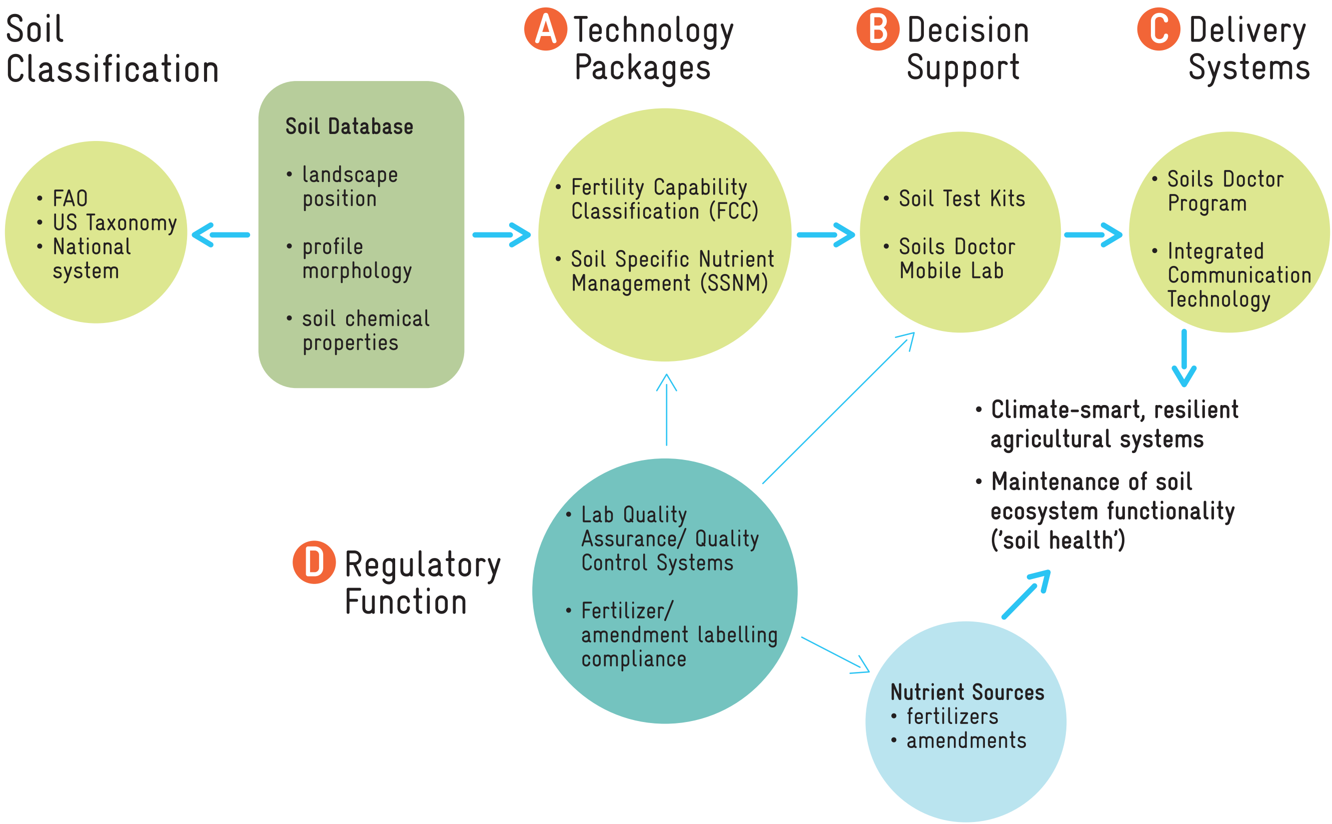
These *Guidelines on Soil and Nutrient Management* and accompanying policy recommendations comprise advice prepared for agricultural decision makers. These decision makers may be a group or person that has the authority to make or to influence policy decisions, whether as a Minister of Agriculture and Forestry in ASEAN or in a member state of ASEAN, a member of an ASEAN Sectoral Working Group on Crops (ASWGC), a project steering committee, or an authority mandated to manage soil and nutrients in the region, including international, regional, and national bodies. The policy recommendations serve to inform how science-based evidence and recommendations on climate-resilient soil and nutrient management can assist in making the best decisions on soil and nutrient management that contribute towards sustaining agricultural production and enhancing food security.

Soil and nutrient management is an integrated system to manage soils, nutrients, water and crops in a sustainable manner to optimise crop production and maintain/improve soil health. These Guidelines provide regionally relevant guidance as a key component of the Strategic Plan of Action for the ASEAN Integrated Food Security (AIFS) Framework. The ultimate objective of the AIFS Framework is to achieve food security of the region by promoting adaptive and resilient 'climate-smart' agricultural systems that underpin a productive and profitable rural sector, while maintaining the functional capacity of the soil resource to provide essential ecosystem functions (commonly described as 'soil health'), including mitigation of emission of greenhouse gases. Climate-smart agricultural systems are necessarily underpinned by the principles of Good Agricultural Practices (GAP), and this dependency is acknowledged in the Guidelines.

Recommendations for implementation of the Guidelines

The *Guidelines on Soil and Nutrient Management* are the technical base of a proposed *Implementation Framework for Soil and Nutrient Management* in the ASEAN region (Fig. A).

Figure A. **Implementation Framework for Soil and Nutrient Management in the ASEAN region.**



This *Implementation Framework for Soil and Nutrient Management* addresses the following goals in the Vision and Strategic Plan for ASEAN Cooperation in Food, Agriculture and Forestry (2016-2025): 'Ensuring food security, food safety and better nutrition', and 'Increasing resilience to, and contributing to, mitigation and adaptation of climate change, natural disasters and other shocks'.

Specifically the *Implementation Framework* addresses Strategic Thrust 3/Action Program 3.1 of this document, namely: 'Effectively implement the ASEAN Integrated Food Security (AIFS) Framework and Strategic Plan of Action on Food Security in ASEAN Region (SPA-FS, 2015-2020)'.

Other Strategic Thrusts/Action Programmes in the ASEAN Vision and Strategic Plan that are also addressed by the *Implementation Framework* include:

- Strategic Thrust 1 (Sustainable 'green' technologies, resource management systems) 1.2, 1.3, 1.4, 1.5, 1.9, 1.12 and 1.13;
- Strategic Thrust 2 (Trade and economic integration) 2.2;
- Strategic Thrust 4 (Resilience to climate change) 4.1, 4.2, 4.3, 4.6, and 4.7.

Implementation of regional soil and nutrient management is necessarily underpinned by: (A) Technology Packages, (B) Decision Support Systems, (C) Delivery Systems and (D) Regulatory Functions (Fig. A). During the development of the Guidelines, the following exemplar packages and systems were identified that could be integrated regionally to achieve the implementation of climate-smart and resilient agricultural systems and maintain/improve soil health:

(A) **The Fertility Capability Classification (FCC)** methodology can be applied to regional soil databases to identify, and provide an inventory of, soil constraints to productive agricultural systems and risk of land degradation. The FCC methodology also identifies management options for amelioration/ mitigation.
Soil Specific Nutrient Management (SSNM) methodology can be used to implement integrated nutrient inputs and practices so that nutrient use efficiency (i.e., nutrient taken up by the crop/ unit of nutrient applied) is optimised for farmer profitability and environmental benefit.

(B) Input information and decision support for SSNM can be provided by **Soil Test Kits** and **Mobile Labs** that provide on-the-spot soil fertility assessment. Ideally, this assessment should be calibrated against crop yield response to provide nutrient recommendations.

(C) Technical advice, training and capacity-building can be delivered regionally by **Integrated Communication Technology (ICT)** and, on-the-ground, by programs such as the **Soils Doctor Program** in Thailand. With further development, ICT could be the primary delivery platform for directly connecting regionally-based technical and extension advice 'hubs' to individual farmers.

(D) Reliable and reproducible analytical data, such as the chemical composition of fertilizer and amendments to meet regulated labelling requirements, and soil and plant analytical input into the FCC and SSNM decision support systems, must be underpinned by certified laboratory **Quality Assurance systems.** Certification for an analysis is evidence that the lab is able to provide reproducible and reliable results in agreement with results from other regional labs. This certification is essential for consistency in regional programs.

Process, outputs, outcomes and timeframes for the implementation of soil and nutrient management in the ASEAN region are documented in Table A.

Table A. **Implementation schedule for soil and nutrient management in the ASEAN region.**

Component	Implementation process	Output	Outcome	Timeframe/ priority
A Technology packages				
Fertility Capability Classification (FCC) *(SNM Guidelines Section 2.2)*	ASEAN Technical Expert Implementation Group	Harmonised set of soil FCC modifiers and constraints for ASEAN region	Regional inventory/ maps of - good quality agricultural land; - soils at risk of degradation; - 'problem soils' *(SNM Guidelines Section 3.1);* - individual soil constraints *(SNM Guidelines Section 3.2)* with associated GSMP *(SNM Guidelines Sections 4.1 - 4.4)*	Short term High priority
Soil Specific Nutrient Management (SSNM) *(SNM Guidelines Section 5.2)*	ASEAN Technical Expert Implementation Group ASEAN Extension Expert Implementation Group	SSNM protocols and nutrient recommendations for rice and maize across the ASEAN region	SSNM protocols and procedures that can be applied to other focus crops across the ASEAN region	Medium term High priority
B Decision support				
Soil Test Kits *(SNM Guidelines Section 5.2)*	ASEAN Technical Expert Implementation Group	Review of soil fertility categories and interpretation guidelines for soil test kits used in the ASEAN region *(SNM Guidelines Section 5.2.1)*	Harmonised soil fertility categories and interpretation guidelines for soil test kits used in the ASEAN region	Medium term Medium priority **Opportunity for public-private partnerships**
Soils Doctor Mobile Lab *(SNM Guidelines Section 5.2)*	ASEAN Technical Expert Implementation Group ASEAN Extension Expert Implementation Group	Mobile soils lab protocols and nutrient recommendations standardised and harmonised with outputs from soil test kits across the ASEAN region	Soil test protocols and procedures that can be applied for soil fertility assessment across the ASEAN region	Medium term Medium priority **Opportunity for public-private partnerships**

Component	Implementation process	Output	Outcome	Timeframe/ priority
C Delivery systems Soils Doctor program	ASEAN Technical Expert Implementation Group ASEAN Extension Expert Implementation Group	Review principles used in the Soils Doctor program for extending technical information on soil and nutrient management to farmers	Principles and guidelines that can be applied for extending technical information on soil and nutrient management to ASEAN farmers *(aligning with the advice on soil and nutrient management practices provided in Sections 4 & 5)*	Short term High priority
Integrated Communication Technology *(SNM Guidelines Section 7.3)*	ASEAN Technical Expert Implementation Group ASEAN Extension Expert Implementation Group	- Implement a dedicated Soil and Nutrient Management page in the 'ASEAN Cooperation on Crops' website. - Develop Soil and Nutrient Management ICT plan for submission to AMAF for support	Interactive information dialogue between farmer and technical/extension experts to provide decision support via Smartphone technology	Long term Medium priority
D Regulatory Functions Lab QA/QC *(SNM Guidelines Section 7.1)*	South East Asian Laboratory Network (SEALNet)	- Uniform Standard Operating Procedures for ASEAN soil testing labs - QA/QC certification program for ASEAN labs	Certification for an analysis is evidence that the lab is able to provide reproducible and reliable results in agreement with results from other regional labs	Medium term High priority
Compliance labelling *(SNM Guidelines Section 6)*	ASEAN Technical Expert Implementation Group	Agreed minimum standards for labelling fertilizers and supplements in the ASEAN region	Harmonised fertilizer and supplement labelling regulations in the ASEAN region	Short term Medium priority

Because of the technical nature of the outputs and expected outcomes, the implementation process will need to be driven by two formalised expert teams comprising nominated scientists/extensionists from ASEAN Member States. The Technical Expert Implementation Group will require knowledgeable and experienced soil scientists with a detailed understanding of agricultural production systems. The Extension Expert Implementation Group will require knowledgeable and experienced agricultural extensionists with a detailed understanding of the socio-economics of rural communities and linkages with agri-business. These two Expert Groups will need to work in close collaboration to review existing information and to facilitate/champion/initiate new activities to achieve the outputs. A process to allow ASEAN policy and planning input into the new activities and outputs will be required to maximise the impact of the outcomes.

PREFACE

Background and Introduction

The ASEAN Guidelines on Soil and Nutrient Management (SNM) have been initiated as a policy tool to contribute to the implementation of the ASEAN Integrated Food Security (AIFS) Framework and its Strategic Plan of Action on Food Security (SPA-FS). The Guidelines have been developed under a regional cooperation project "ASEAN Sustainable Agrifood Systems (ASEAN SAS), a module of the ASEAN - German Program on Response to Climate Change in Agriculture and Forestry (GAP-CC). The Program is commissioned by the Federal Ministry for Economic Cooperation and Development (BMZ) and implemented by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. The objective of the GAP-CC program is to support ASEAN in developing and implementing regionally coordinated policies and strategies to address climate change in the agriculture and forestry sectors.

Implementation Mechanism for Development of the Guidelines

Regional implementation

Development of the Guidelines was conducted by the Regional Expert Group on Soil and Nutrient Management comprised of nominated senior experts from national Departments mandated to lead policy and initiatives on soil and nutrient management in the respective ASEAN Member States (AMS). Project Coordination Unit (PCU) of the ASEAN SAS facilitated and coordinated the implementation at regional level, in collaboration with the Department of Agriculture (DOA) of Thailand, the host country of the project.

National Implementation

At national level, respective AMS nominated representatives to the Regional Expert Group from the respective national Departments mandated to develop policy and initiatives on soil and nutrient management. These Departments are responsible for overseeing the implementation process at national level and serve as the lead agency to coordinate preparation of national contents in accordance with regional agreements. The implementation at national level is executed through the National Working Group of Experts led and directed by the respective AMS's representative on the Regional Expert Group.

The national lead Departments actively ensure involvement and participation of all key stakeholders in the implementation process, and are responsible for consultation and cooperation arrangements with relevant government and non-government agencies, including active engagement with local communities at national level.

Development Process

The Regional Expert Group was responsible for writing the content of the Guidelines through the support of the National Working Groups. In preparing the content, a number of regional and national consultative meetings and workshops were conducted to obtain inputs for the Guidelines. These meetings and workshops served as platforms for expert groups to share knowledge and experience, including discussion and review of contents. The contents presented in these Guidelines are derived from inputs provided by AMS. The inputs received comprise of scientifically proven management practices that are location - and situation - specific, ranging from indigenous practices and field - tested crop management measures to knowledge - based options. They can be modified or adjusted to be applicable in other areas with similar conditions.

To complete the task, involvement of *relevant key stakeholders throughout the development process is the key to success.* As mentioned earlier various organizations/sectoral working groups/joint committees/expert working groups were engaged, interacted and contributed to support the development at deferent levels, namely practitioner/farmer level, technical level and policy level. Ensuring efficacy of implementation of the guidelines, technical expert groups (agriculturist and soil scientist) play key role to support develop policy recommendations concern and strengthening linkages between key stakeholders and making information available to support the greater use of soil resource information for sustainable agriculture in ASEAN Member States. They act as the link between policy maker and practitioner/farmer, on one hand to bridge the communication gap (science & policy) between policy maker and scientist. On the other hand to connect ground practice & scientific knowledge gap between expert/researcher and farmer, thereby fulfill the implementation gap through evidence-based policy recommendations.

ASEAN SNM Guidelines strongly support and contribute to the global efforts addressing climate change adaptation and mitigation. The Guidelines promote sustainable soil and nutrient management, enhancing soil productivity and functionality to optimize crop production and ecosystem services, thereby enabling smallholder farmers to increase adaptability and resiliency to changing climate. The Guidelines are therefore closely aligned with the Global Agenda for Sustainable Development (Sustainable Development Goals: 2 & 13). The proven practices documented in the Guidelines with technical guidance and accompanying policy recommendations are in consonance with the Five Pillars of Action of Global Soil Partnership. They are the perfect complement to the *Voluntary Guidelines for Sustainable Soil Management,* endorsed by FAO Council in December 2016, and provide opportunities for facilitating and implementing the principles underpinning the Global Soil Partnership.

GLOSSARY

ASEAN SAS	ASEAN Sustainable Agrifood Systems
ASS	Acid Sulfate Soil
AWD	Alternate Wetting and Drying
BRIS	Beach Ridges Interspersed with Swales
CA	Conservation Agriculture
CEC	Cation Exchange Capacity
C:N ratio	Carbon to Nitrogen ratio
CT	Conventional Tillage
DMC/CA	Direct-Seeding Mulch-Based Conservation Agriculture
ESP	Exchangeable sodium percentage
FCC	Fertility Capability Classification
GAP	Good Agricultural Practices
GAP-CC	ASEAN-German Program on Response to Climate Change in Agriculture and Forestry
GNMP	Good Nutrient Management Practices
GQAL	Good Quality Agricultural Land
GSMP	Good Soil Management Practices
GPS	Global Positioning System
ICT	Integrated Communication Technology
IFOAM	International Foundation for Organic Agriculture
ISO/IEC	International Organization for Standardization/International Electrotechnical Commission
LCC	Leaf Colour Chart
NT	No-Till
NV	Neutralizing Value
SALT	Sloping Agricultural Land Technology
SEALNet	South East Asian Laboratory Network
SNM	Soil and Nutrient Management
SRI	System of Rice Intensification
SS	Sediment Storage
SSNM	Site/Soil Specific Nutrient Management
WEPAL	Wageningen Evaluating Programmes for Analytical Laboratories (Wageningen University, Netherlands)

Organizations

AMS	ASEAN Member States
AMAF	ASEAN Ministers on Agriculture and Forestry
ASEAN	Association of Southeast Asian Nations
ASWGC	ASEAN Sectoral Working Group on Crops
DOA	Department of Agriculture
FAO	Food and Agriculture Organization of the United Nations
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
ITU	International Telecommunication Union
PCU	Project Coordination Unit
SC	Steering Committee
SOM-AMAF	Senior Officials Meeting of the ASEAN Ministers on Agriculture and Forestry
UNESCO	United Nations Educational, Scientific and Cultural Organization
USEPA	United States Environmental Protection Agency

Member States

BRN	Brunei Darussalam
IDN	Republic of Indonesia
KHM	Kingdom of Cambodia
LAO	Lao People's Democratic Republic
MYN	Republic of the Union of Myanmar
MYS	Malaysia
PHL	Republic of Philippines
SGP	Republic of Singapore
THA	Kingdom of Thailand
VNM	Socialist Republic of Vietnam

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1. INTRODUCTION

1.1 Rationale of the Guidelines

Soil and nutrient management is an integrated system to manage soils, nutrients, water and crops in a sustainable manner to optimise crop production and improve soil health. The development of ASEAN Guidelines on Soil and Nutrient Management (SNM) is designed as a tool to provide regionally coordinated guidance, and to facilitate decision-making in formulation of policy recommendations on soil and nutrient management. The ultimate objective is to achieve food security of the ASEAN region by promoting adaptive and resilient 'climate-smart' agricultural systems that underpin a productive and profitable rural sector, while maintaining the functional capacity of the soil resource to provide essential ecosystem functions (commonly described as 'soil health'), including mitigation of emission of greenhouse gases.

1.2 Purpose and structure of the Guidelines

These Guidelines are intended to provide guidance to the policy, planning and technical support services of government, but the requirements of these different end-user groups are diverse. Consequently a scoping analysis was undertaken of the issues and responses of these end-user groups so the Guidelines could be framed to meet their requirements. Table 1 lists the motivations, issues and responses of government policy, planning and support services associated with the rural sector. The responses are primarily regulatory, monitoring/evaluation and capacity-building in nature.

Table 1 **User motivations, issues and responses with respect to soil and nutrient management.**

User	Motivation	Issues	Response
Government sector-Policy	- Food security	- Biosecurity threats	- Regulations
		- Decline of soil quality/health	- Inventory and monitoring of soil quality/health
	- Climate change	- Rising sea level	- Risk assessment of inundation and salinisation
		- Changing rainfall/ temperature trends	- Irrigation planning - Resilient 'climate-smart' agricultural systems
		- Greenhouse gases emission abatement	- Facilitate improved agricultural nitrogen use efficiency to reduce nitrous oxide emissions - Encourage balanced use of organic and inorganic forms of nutrients to promote all sources of nutrient supply, thereby improving plant productivity and facilitating carbon sequestration. - Provide guidance on improved soil drainage management to mitigate methane emissions from soil.
Government sector-Planning	- Alienation of Good Quality Agricultural Land (GQAL)	- Reduced area of arable land due to urbanisation/ infrastructure/ contamination	- Urban/regional planning processes and legislation
Government sector-Support services	- Productive and resilient rural sector	- Uninformed decision-making by farmers	- Capacity-building by informed extension services - Science-based decision support systems/tools

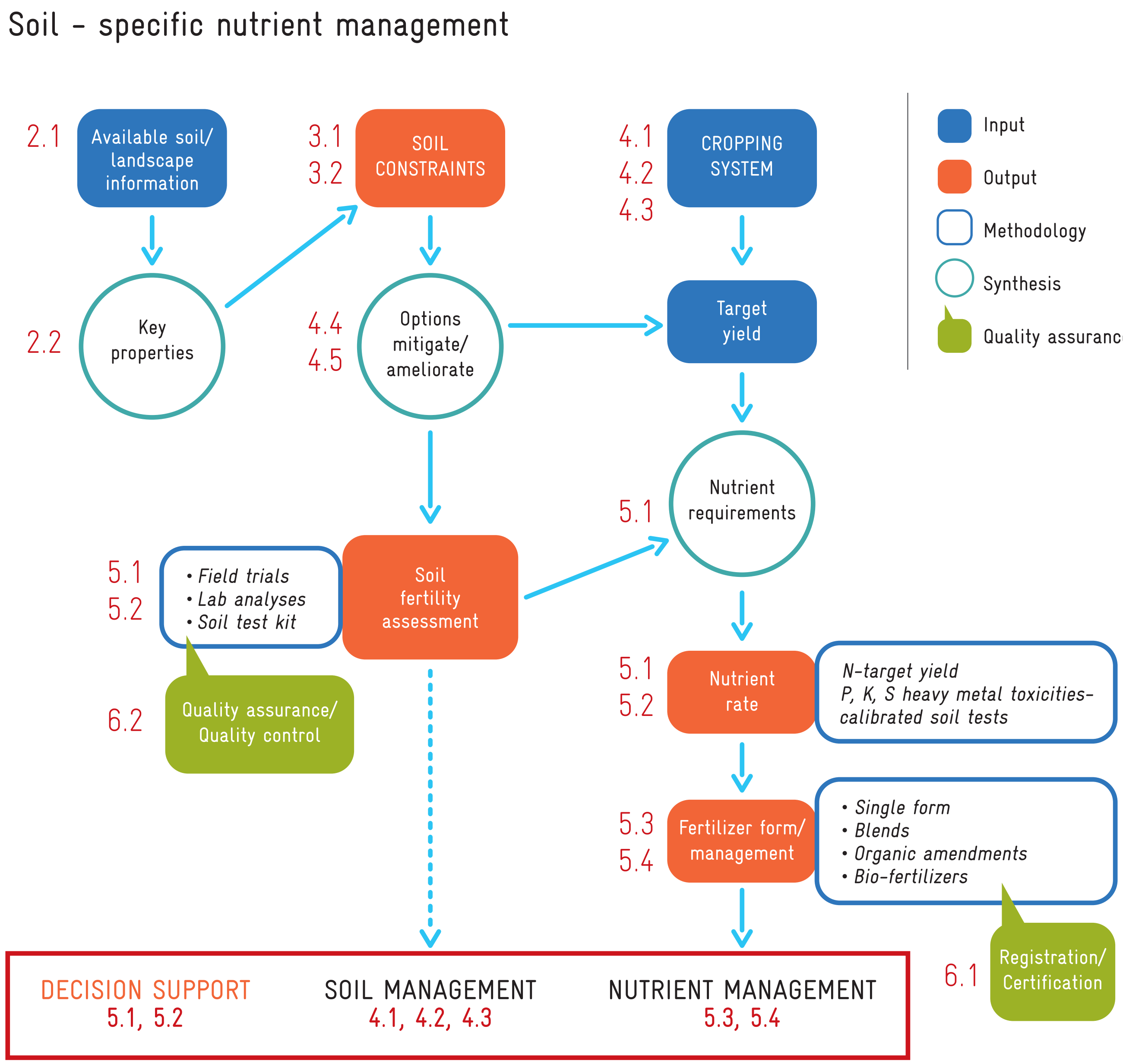
The information required from the Guidelines to meet end-user group responses was identified and used to frame the Guidelines so that they provide the required outputs. Outputs are essentially information, methodology, interpretive guidelines, decision support tools and proven technology 'packages' that maintain/improve the productive capacity of the soil resource (Table 2).

Table 2 **Information required from the Guidelines on Soil and Nutrient Management to meet user needs.**

Motivation	Response	Required information	Information format
- Food security	- Regulations - Inventory and monitoring of soil quality/health - *Risk assessment of inundation, salinisation*	*Out of scope of Guidelines* Methodology and interpretive guidelines for categorising and monitoring key soil properties. *Out of scope of Guidelines*	 - Text - Spatial
- Climate change	- Irrigation planning - Resilient 'climate-smart' agricultural systems	Nutrient requirements of key crops in water use efficient/climate change resilient cropping systems.	- Text
- Alienation of Good Quality Agricultural Land (GQAL)	- Urban/regional planning processes and legislation	Methodology and interpretive guidelines for soil properties considered to be essential for productive arable soils.	- Text - Spatial
- Productive and resilient rural sector	- Capacity-building by informed extension services	Methodology and interpretive guidelines for identifying and managing soil constraints. Soil and nutrient management 'packages' for delivery to farmers based on the principles of soil/site specific management	- Text - Spatial - Text - Web-based

To provide structure to the Guidelines and to facilitate their use, a 'map' was developed so the end-user can quickly identify the section of the Guidelines that is of interest to them (Fig. 1).

Figure 1 **Map of inputs, outputs, methodology and synthesis sections of the Guidelines on Soil and Nutrient Management.**



The Guidelines have two parallel streams – soil management and crop management – that interact in a cropping system context. The concept of **Site/Soil Specific Nutrient Management' (SSNM)** integrates soil and crop management and best addresses the issue of sustainability (Fairhurst et al., 2007). A brief description of SSNM is that soil constraints to crop production at a site are identified using relevant soil information/local wisdom, and amelioration/mitigation options are then considered. If resources permit, amelioration or mitigation is undertaken to increase the productive potential of the site. The target yield is then used to determine nutrient requirements. These nutrient requirements can be met from multiple sources including the soil itself, inorganic fertilizers, and added organic material such as crop residues, composts, and manures. **Integrated Nutrient Management** aims to utilise all available nutrient sources as effectively as possible, and the ultimate goal (and the key performance indicator) is to maximise crop recovery of applied nutrients, thereby minimising nutrient loss off – site.

Implementation of **Site/Soil Specific Nutrient Management** underpinned by **Integrated Nutrient Management** across the ASEAN region is essential for securing food security with adaptive and resilient 'climate – smart' agricultural systems that maintain the ecosystem functionality of the soil resource.

2. SOIL RESOURCES IN THE ASEAN REGION

2.1 Major soil types

There is a wide diversity in the quality, scale and comprehensiveness of soils data across the ASEAN region. **Attachment 1** provides metadata for national soil survey information in the ASEAN region. The scale of digitised soil data ranges from 1:25,000 (Thailand) to 1:5,000,000 (FAO, 1979) and the soil taxonomy systems used as the mapping units comprise FAO-UNESCO (1974), US Soil Taxonomy (Soil Survey Staff, 2003) and unique former national classification systems [viz. Vietnam (National Institute for Soils and Fertilizers, 2002), Thailand, and the Philippines (Carating et al., 2014)].

It is not generally possible to convert one soil classification system to another with any precision, but undertaking this exercise is useful to the extent that it allows essential differences in the soil resources across the ASEAN region to be highlighted. The FAO-UNESCO soil classification system has become the de-facto international soil classification system, and Table 3 indicates the approximate percentage of land area covered by FAO-UNESCO soil groups in the ASEAN member states.

Table 3 **Proportional area of FAO-UNESCO Soil Groups (FAO 1974) in the ASEAN region.**

FAO-UNESCO Soil Group	BRN	KHM[A]	IDN	LAO[B]	MYS[C]	MMR	PHL	THA	VNM[D]
	(%)								
Acrisols	57	14	29	73	62	10	25	38	63
Alisols									1
Andosols			4				4		
Arenosols				3	3		1	2	2
Cambisols		2	35	12	11	28	11	2	
Ferralsols			12	1	4	39		<1	8
Fluvisols	13	27	10	1	3	2	<1	1	18
Gleysols	10	12		2	4	14	2	8	2
Histosols	10		8		8			<1	
Leptosols				1				1	1
Lixosols				1					

FAO-UNESCO Soil Group	BRN	KHM[A]	IDN	LAO[B]	MYS[C]	MMR	PHL	THA	VNM[D]
	(%)								
Luvisols		28		4	3	3	11	8	
Nitosols		1				3	42		
Plinthosols								5	
Podzols					2			<1	
Regosols				2					
Vertisols	10	16	2			1	4		
Slope complex[E] (Thailand; Vietnam)								32	5

[A]Rice soils only (White et al., 1997); [B]Soil Survey Land Classification Centre, National Agriculture and Forestry Research Institute, 2015; [C]Department of Agriculture (Peninsular Malaysia, Sabah and Sarawak), 2004 (unpubl. data) UNESCO; [D]Vietnam Soil Science Society, 2000; [E]Slope > 35%.

Differences among ASEAN member states in their soil resources are evident at this very coarse scale of resolution. Acrisols predominate in Brunei Darussalam, Lao PDR, Malaysia, Thailand and Vietnam. Cambisols predominate in Indonesia and are also prevalent in Myanmar, together with Ferralsols. Nitosols predominate in the Philippines, while in the rice-producing soils of Cambodia, Fluvisols and Luvisols are the major soil groups.

General soil chemical and physical characteristics associated with the FAO-UNESCO soil groups (Driessen et al., 2001) are presented in Table 4.

Table 4 **General chemical and physical characteristics associated with the major FAO-UNESCO soil groups occurring in the ASEAN region (Driessen et al., 2001).**

Soil Group	Characteristics
Acrisols	Acidic soils with low base cation status; formed under conditions of strong leaching; increase in clay content in the subsoil; may have hard-setting surface characteristics; low soil fertility status; low soil biological activity.
Alisols	Strongly acidic soils with a marked textural increase in the subsoil with predominantly high activity clays that are base unsaturated. The clayey subsoil may have limited permeability causing seasonal perched watertables. Surface soil structure is often unstable, making these soils susceptible to erosion. Low soil fertility is a consequence of the soil acidity and low base saturation, and aluminium and manganese toxicities are common.

Soil Group	Characteristics
Andosols	Soils derived from recent volcanic deposits; accumulation of stable organo-mineral complexes and short-range-order minerals such as allophanes (hydrous alumina-silicates); very high moisture content at permanent wilting point but moderate plant available water-holding capacity; excellent internal drainage; generally resistant to erosion because of good aggregate stability; high phosphorus fixation because of the high content of active aluminium.
Cambisols	Brown soils with a weakly developed subsoil; loamy to clayey texture; generally well-structured with a moderate plant available water-holding capacity; slightly acidic to neutral pH; satisfactory soil fertility; risk of landslip if deforested on sloping land.
Ferralsols	Strongly leached soils of clay loam texture and low activity clays (iron and aluminium hydrous oxides); good infiltration and internal drainage; limited plant available water-holding capacity; typically low fertility status and high P fixation capacity; stable aggregates that resist erosion and make tillage easy.
Fluvisols	Recent alluvial soils of depositional origin rather than weathered in situ; saturated for prolonged periods because of their low-lying position in the landscape; generally near neutral pH; often initially fertile.
Gleysols	Soils whose surface horizon is saturated for prolonged periods because of their low-lying position in the landscape; characteristic pale-grey colour in the permanently saturated subsoil and mottling in the upper soil profile where a fluctuating water table occurs; neutral pH when flooded; often initially fertile.
Histosols	Peat soils occurring in mangroves and swamps with > 20% organic matter by weight and generally > 85% porosity; in the 'raw' state, peat soils are often very acidic, nutrient poor, and with low microbial activity. Prone to subsidence if drained.
Luvisols	Slightly acidic soils that have a marked textural increase in the subsoil due to an accumulation of clay. These soils are generally permeable, and the clay-enriched subsoil has a moderate plant available water-holding capacity.
Nitisols	Tropical soils with clayey subsoils; deep, well-drained, red; generally fertile although P status may be low; low plant available water-holding capacity; moderate cation exchange capacity.
Plinthosols	Soils that contain an iron-rich, humus-poor hardpan layer comprising kaolinitic clay and quartz. The hardpan layer restricts root penetration and water infiltration and consequently root zone volume is restricted. These soils often have low plant available water-holding capacity and are of low fertility.
Vertisols	Neutral to alkaline clay soils that crack when dry and swell when re-wet; major constraint is the narrow range of soil moisture in which tillage can occur-tillage is difficult when the soil is dry, and can only occur when the soil is close to, but not at, field capacity; typically high cation exchange capacity; moderate-high plant available water-holding capacity; often initially fertile.

Table 5 indicates the major crops grown on the various soil groups in the ASEAN region.

Table 5 **Major crops grown in the ASEAN region on the FAO-UNESCO soil groups.**

Soil Group	Major Crops
Acrisols	Upland rice, paddy rice, soybean, maize, groundnut, cassava, tea, coffee, rubber, pineapple, sugarcane, banana, cashew
Alisols	Upland rice, paddy rice, soybean, maize, cassava, coffee
Andosols	Forest, vegetables
Arenosols	Forest, paddy rice, maize, groundnut, cassava, coconut, watermelon, pineapple
Cambisols	Forest, fruit trees, rubber, mango, pineapple, soybean, maize, cassava, coffee
Ferralsols	Forest, rubber, mango, pineapple, tea, coffee, durian, cassava, banana, coconut and oil palm, tea, durian, cocoa, mulberry
Fluvisols	Rice, jute, sugarcane, maize, sesame, groundnut, chilli, vegetables, mango
Gleysols	Paddy rice, raised beds with sesame, groundnut, maize, cotton, vegetables, sugarcane, jute, sorghum
Histosols	Vegetables, paddy rice with zero till, oil palm
Leptosols	Forests, paddy rice
Lixosols	Forest, soybean, maize, cassava, coffee, rubber
Luvisols	Paddy rice, sesame, sunflower, groundnut, cotton, sugarcane, chilli, vegetables, mango
Nitosols	Forest, groundnut, sesame, soybean, maize, cassava, coffee, rubber, tea, durian
Plinthosols	Forest
Podzols	Vegetables, water melon, ginger, turmeric, coconut, cashew
Regosols	Forest
Vertisols	Paddy rice, sesame, sunflower, groundnut, cotton, sugarcane, chilli, vegetables

2.2 Soil characteristics

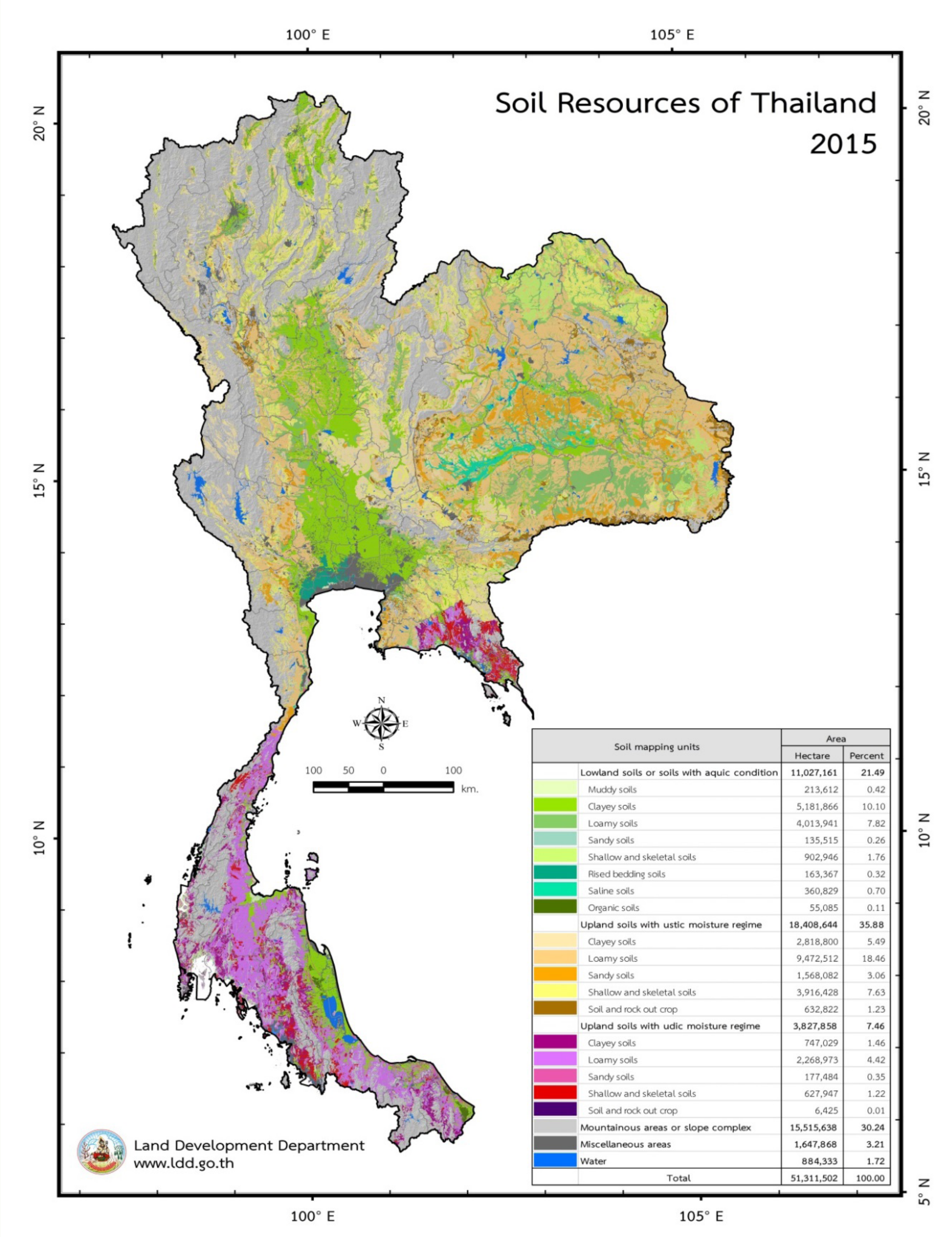
Soil classification is based on the measurement and description of several characteristics of representative soil profiles that are indicative of soil-forming processes. However, these characteristics can also be used singly, or in combination, to generate soil datasets or maps that categorise soils according to the specific requirements of an end-user. For example, Figure 2 (Land Development Department, 2015) is a map of Thailand based on elevation (upland/lowland), soil moisture regime (aquic/ustic/udic), soil texture (clayey/loamy/sandy/skeletal) and specific soil characteristics (saline/organic). This map is based on outputs from the same soil database that was used for assigning soil type classification. Likewise, Carating et al. (2014) defined nine major Soil Profile Groups for soils of the Philippines based on landscape position, parent material, texture, drainage, permeability, and soil structure. Grouping soils on the basis of these easily recognisable features is very instructive for inferring much useful soil fertility and soil management information. For example, soil texture in combination with clay mineralogy determines many important soil properties such as cation exchange capacity, phosphorus fixation, resistance to accelerated acidification caused by land use, and plant available water capacity.

These relationships underpin the Fertility Capability Classification (FCC) system (Sanchez et al., 1982) which assigns diagnostic criteria based on key soil attributes to identify individual soil constraints. These attributes can either be derived from simple field observations and measurements made at point scale [e.g., White et al. (1997) for rice soils in Cambodia; Moody and Cong (2008) for upland soils in Vietnam] or sourced from soil survey data [e.g., Ringrose-Voase et al. (2008) for Brunei Darussalam].

Table 6 indicates the key soil attributes that can be used to identify or infer the soil constraints listed in Section 3.2 from either field observations or quantitative soil survey data.

With respect to assessing soil fertility, specific soil chemical analyses have been used to generate generalised 'soil fertility' categories in some ASEAN Member States (Table 7). When the same soil test methods are used, there is loose agreement for some categories (e.g., organic C, total N, CEC), but markedly different values for categories of other soil tests (e.g., Bray II). This disparity highlights the problem of deciding what crop or land use is being used to benchmark soil fertility is it low input systems such as upland cropping or high input systems such as vegetable cropping. This soil fertility benchmarking problem has been addressed in Brunei-Darussalam by developing individual 'optimum ranges' for soil macro-and micro-nutrients for vegetables, paddy rice and perennial fruit crops (Department of Agriculture and Agrifood, Ministry of Primary Resources and Tourism).

Figure 2 **Soil resources map of Thailand**



Soil mapping units	Area	
	Hectare	Percent
Lowland soils or soils with aquic condition	**11,027,161**	**21.49**
Muddy soils	213,612	0.42
Clayey soils	5,181,866	10.10
Loamy soils	4,013,941	7.82
Sandy soils	135,515	0.26
Shallow and skeletal soils	902,946	1.76
Rised bedding soils	163,367	0.32
Saline soils	360,829	0.70
Organic soils	55,085	0.11
Upland soils with ustic moisture regime	**18,408,644**	**35.88**
Clayey soils	2,818,800	5.49
Loamy soils	9,472,512	18.46
Sandy soils	1,568,082	3.06
Shallow and skeletal soils	3,916,428	7.63
Soil and rock out crop	632,822	1.23
Upland soils with udic moisture regime	**3,827,858**	**7.46**
Clayey soils	747,029	1.46
Loamy soils	2,268,973	4.42
Sandy soils	177,484	0.35
Shallow and skeletal soils	627,947	1.22
Soil and rock out crop	6,425	0.01
Mountainous areas or slope complex	**15,515,638**	**30.24**
Miscellaneous areas	**1,647,868**	**3.21**
Water	**884,333**	**1.72**
Total	51,311,502	100.00

Table 6 **Soil constraints and diagnostic indicators for their identification using either point-scale field observation or spatial soil survey data. Point-scale field observations are made on a 0-50 cm mini-soil pit (Source: Moody and Cong, 2008; White et al., 1997).**

Soil constraint	Diagnostic indicators	
	Field observation	Soil analysis
Acidity	Field measured soil pH < 5.0	Soil $pH_{1:2.5water}$ < 5.0 except peat soils where $pH_{1:2.5water}$ < 4.5; Al toxicity risk: > 10% Al saturation of ECEC or > 11% Al saturation of CEC $_{pH7.0}$ Al toxicity: > 60% of ECEC
Alkalinity	Field measured soil pH > 8.0; effervescence when dilute acid is added to the soil due to the presence of carbonates.	Soil $pH_{1:2.5water}$ > 8.0; free $CaCO_3$ measured by calcimeter
Sodicity	Field measured soil pH > 9.0; soil aggregates disperse when immersed in water; bare soil scalds.	Exchangeable sodium percentage (ESP) of CEC > 15%; Sodicity risk: ESP 6-15%
Salinity	Visible salt crusts; evidence of saline seepage; soil occurs on lower concave slopes of cleared land.	Electrical conductivity (saturation extract) > 4 dS/m; Salinity risk for sensitive crops: Electrical conductivity (saturation extract) > 2 dS/m
Acid sulfate	Presence of a sulfidic layer. Field measured soil pH < 4 after oxidation with 30% hydrogen peroxide (adjusted to pH 5.5).	Soil $pH_{1:2.5water}$ < 4 after oxidation with 30% hydrogen peroxide
Low nutrient retention	Sandy texture; clay loam texture + red soil colour + acidic soil pH (i.e., Ferralsols).	ECEC < 4 $cmol_c$/kg or $CEC_{pH7.0}$ < 7 $cmol_c$/kg
High P fixation	Clay loam texture+ red soil colour + acidic soil pH (i.e., Ferralsols); soils formed on volcanic ejecta (i.e., Andosols).	P Buffer Index (Burkitt et al., 2002) > 280
Waterlogging	Gleyed soil colour (pale-grey) (i.e., Gleysols); mottling (red/yellow) in upper soil profile; low lying position in the landscape; soil saturated for > 60 days/year.	measure soil Eh

Soil constraint	Diagnostic indicators	
	Field observation	Soil analysis
Low plant available water-holding capacity	Sandy texture; clay loam texture + red soil colour + acidic soil pH (i.e., Ferralsols).	Particle size analysis: sand > 80%; ECEC < 4 $cmol_c$/kg or $CEC_{pH7.0}$ < 7 $cmol_c$/kg
Hard setting	Silty texture; aggregates disperse or slake when immersed in water; surface crusting.	Particle size analysis: silt > 70%
Compaction	Platy soil structure; root growth deflected when contacting the compaction layer; resistance to insertion of a pointed rod when soil is at field capacity.	Particle size analysis: clay > 20%
Susceptibility to erosion	Slope position in landscape; visible evidence of sheet/rill/gully erosion; soil aggregates disperse or slake when immersed in water.	

Soil $pH_{1:2.5water}$: Soil pH measured at 1:2.5 soil:solution ratio in water; ECEC: Effective cation exchange capacity; $CEC_{pH7.0}$: Cation exchange capacity measured at pH7.0

Table 7 Categories used in the ASEAN region to give generalised soil fertility ratings

Parameter	BRN	IDN[A]	KHM[B]	LAO	MYS[C]	PHL	SGP	THA	VNM[D]
Organic C (%)	Method: Walkley - Black Low < 1.0 Medium 1.0 - 1.9 High ≥ 2.0	Method: Walkley - Black Very low <1 Low 1 - 2 Medium 2 - 3 High 3 - 4	Method: Walkley - Black Very low < 0.4 Low 0.4 - 0.7 Medium 0.8 - 1.7 High 1.7 - 2 Very high > 2	Method: Walkley - Black Low < 0.9 Medium 1.0 - 1.9 High ≥ 2.0	Method: Combustion Low < 1.4 Medium 1.5 - 2.9 High ≥ 3.0	Method: Walkley - Black Low < 0.6 High 0.6 - 4.7		Method: Walkley - Black Low < 1.5 Medium 1.5 - 3.5 High ≥ 3.5	Method: Walkley - Black Low < 0.9 Medium 1.0 - 1.9 High ≥ 2.0
Total N (%)		Method: Kjeldahl Very low < 0.1 Low 0.1 - 0.2 Medium 0.21 - 0.5 High 0.51 - 0.75	Method: Kjeldahl Very low < 0.1 Low 0.1 - 0.15 Medium 0.15 - 0.25 High 0.25 - 0.5 Very high > 0.5	Method: Kjeldahl Low < 0.15 Medium 0.15 - 0.25 High > 0.25	Method: Combustion Low < 0.14 Medium 0.15 - 0.26 High ≥ 0.27	Method: Kjeldahl Low < 0.1 High 0.1 - 0.4	Method: Kjeldahl Low < 0.15 Medium 0.15 - 0.20 High > 0.20	Method: Kjeldahl Low < 0.1 Medium 0.1 - 0.2 High > 0.2	Method: Kjeldahl Low < 0.1 Medium 0.1 - 0.2 High > 0.2
Extractable P (mg P/ kg soil)	Method: Bray II Low < 21 Medium 21 - 30 High > 30	Method: Bray II Very low < 4 Low 5 - 7 Medium 8 - 10 High 11 - 15	Method: Bray II Very low < 15 Low 15 - 20 Medium 20 - 40 High 40 - 100 Very high > 100	Method: Bray II Low < 10 Medium 10 - 25 High > 25	Method: Bray and Kurtz Low < 10 Medium 10 - 15 High > 15	Method: Bray I Low < 6 Medium 6 - 10 High 7 - 10	Method: Mehlich 3 Low < 30 Medium 30 - 60 High > 60	Method: Bray II Low < 10 Medium 10 - 25 High > 25	Method: Bray II Low < 21.8 Medium 21.8 - 43.6 High > 43.6
Extractable K (mg K/ kg soil)	Method: NH_4 Ac, pH 7 Low: < 78 Optimum: 78 - 117 High: > 117	Method: NH_4 Ac, pH 7 Very low < 10 Low 10 - 30 Medium 40 - 50 High 60 - 100	Method: NH_4 Ac, pH7 Very low < 5 Low 5 - 15 Medium 15 - 30 High 30 - 60 Very high > 60	Method: NH_4 Ac, pH 7 Low < 60 Medium 60 - 90 High > 90	Method: NH_4 Ac, pH 7 Low < 90 Medium 90 - 150 High > 150	Method: NH_4 Ac, pH 7 Low < 58 Medium 58 - 98 High > 98	Method: Mehlich 3 Low < 150 Medium 150 - 300 High > 300	Method: NH_4 Ac, pH 7 Low < 60 Medium 60 - 90 High > 90	Method: NH_4 Ac, pH 7 Low < 83 Medium 83 - 166 High > 166
CEC ($cmol_c$/kg)		Method: NH_4 Ac pH 7 Very low < 5 Low 5 - 16 Medium 17 - 24 High 25 - 40	Method: NH_4 Ac pH 7 Very low < 6 Low 6 - 12 Medium 12 - 25 High 25 - 40 Very high > 40	Method: NH_4 Ac pH 7 Low < 10 Medium 10 - 20 High > 20	Method: NH_4 Ac pH 7 Low < 10 Medium 10 - 15 High > 15	Method: NH_4 Ac pH 7 Low < 10 Low 5 - 16 Medium 10 - 20 High > 20	Method: NH_4 Ac pH 7 Low < 10 Medium 10 - 20 High > 20	Method: NH_4 Ac pH 7 Low < 10 Medium 10 - 20 High > 20	Method: NH_4 Ac pH 7 Low < 10 Medium 10 - 20 High > 20

[A]Eviati and Sulaeman (2012); [B]Kanapathy (1976); [C]Vietnam Soil Science Society, 2000

3. SOIL CONSTRAINTS TO LAND USE

Soil provides the essential requirements for plant growth: nutrients, water, oxygen and physical support. However, the extensive variety of parent materials, environmental conditions and soil-forming processes results in soils with a wide range of chemical and physical characteristics that might constrain crop growth and which must be managed to achieve sustainable production. Identifying the constraint(s) is the first step towards deciding appropriate management strategies.

3.1 Problem soils

While specific constraints can often be associated with particular FAO-UNESCO soil groups (e.g., low nutrient retention by Acrisols; high phosphorus fixation by Ferralsols), there are 'problem soils' (often identified with local wisdom or indigenous knowledge) that exhibit particular constraints due to their soil-forming processes (e.g., acid sulfate soils), parent material (e.g., peat soils), or texture (e.g., sandy soils). These soils have one or more constraints that must be addressed to increase productivity, and often have a specific management package tailored to achieve this outcome.

3.1.1 Acid sulfate soils

Acid sulfate soils form when sulfate-rich sea water mixes with iron-rich coastal terrestrial deposits and organic matter under anaerobic (waterlogged) conditions. Pyrites (iron sulphides) are formed. Upon drainage, the sulfide oxidizes to form sulfuric acid and the pH drops below 3.5 within a short time period (days to weeks). The acidification causes the release of toxic levels of iron, aluminium and heavy metals.

Under natural conditions, these soils do not pose any agricultural production or environmental problems. But when drained, the pyrite reacts with oxygen in the air and sulfuric acid forms. Jarosite, [$KFe_3(SO_4)_2(OH)_6$], is the main product of pyrite oxidation and can be recognized by the presence of yellowish precipitates/bright yellow or straw-coloured mottles with dark-reddish streaks of iron oxide

Acid sulfate soils are generally unproductive due to excessive acidity, salinity, aluminium toxicity, iron toxicity, low content of major nutrients, low base status and hydrogen sulfide toxicity.

It is estimated that there are 27,000 ha of acid sulfate soils in the Philippines (Recel, 1989), 187,000 ha in Peninsular Malaysia plus 571,000 ha in Sarawak plus 270,000 ha in Sabah (Abdul Jamil, 1993), 1.8 million ha in Thailand (Land Development Department, 2006) and 2 million ha in Vietnam (National Institute for Soils and Fertilizers, 2002).

3.1.2 Peat soils

Peat soils have a high content of organic carbon (> 12%). This high amount of organic matter originates from accumulated plant materials that once vegetated the area, died, and partially decayed under waterlogged or reduced conditions that prevented them from rapidly decomposing. Peat soils shrink irreversibly when drained, and can catch fire when dried.

It is estimated that there are 15,000 ha of peat soils in the Philippines (Recel, 1989), 55,000 ha in Thailand (Land Development Department, 1990), 100,000 ha in Brunei Darussalam (Ringrose-Voase et al., 2008), 535,000 ha in Vietnam (National Institute for Soils and Fertilizers, 2002) and 2.7 million ha in Malaysia (Matulib et al., 1991). Indonesia has 14.9 million ha of peat soils (Ritung et al., 2015)

Crops (such as rice) grown on peat soils are generally low-yielding due to deficiencies of nitrogen, phosphorus and zinc (Lantin et al., 1990). Salinity is associated with coastal peats and iron toxicity with acid peats.

Photo 1 **Extensive subsidence is one of the major problems of drained peat soils.**

3.1.3 Sandy soils

Sandy soils have a relatively deep profile (>1 metre) with less than 10% clay throughout and single grain structure. These soils are generally a component of coastal sand dune systems and may have either saline water tables [e.g., Beach Ridges Interspersed with Swales (BRIS) occurring in Malaysia] or perched freshwater lakes (e.g., central coastal Vietnam) associated with them. Deep sandy soils have low plant available water-holding capacity, low nutrient retention because of low cation exchange capacity (CEC), and generally low organic matter content and fertility. They have low intrinsic pH buffer capacity and are therefore prone to rapid acidification if cropped intensively and/or fertilised with ammonium-based fertilizers. It is estimated that there are 608,000 ha of sandy soils in Myanmar (Department of Agriculture, Ministry of Agriculture and Irrigation, 2016). In Malaysia, BRIS soils cover an area of about 195,800 ha - 155,400 ha in Peninsular Malaysia and 40,400 ha in Sabah (Thomas, 1966).

3.1.4 Skeletal soils

Skeletal or shallow soils are characterised by layers of dense laterite, gravel, rock debris or marl shallower than 25 cm from the soil surface. These layers impede the penetration of plant roots and are a major constraint to tillage operations. Because of the intractable layer, effective rooting depth is restricted thereby causing severe limitations to the quantities of water and nutrients available for crop uptake. These soils are typically very susceptible to drought and nutrient deficiencies. It is estimated there are 0.5 million ha of skeletal soils in Vietnam (National Institute for Soils and Fertilizers, 2002) and 5.5 million ha in Thailand (Land Development Department, 1990).

3.1.5 Contaminated and disturbed soils

A contaminated soil is one containing substances that pose an ecological or biological risk, and which are either not present in the natural environment (e.g., manufactured organic compounds) or are present at concentrations higher than occur in the natural environment (e.g. heavy metals). The concern over soil contamination comes primarily from health risks (human and animal), from direct contact with the contaminated soil, vapours from the contaminants, and from secondary contamination of water supplies within and underlying the soil (USEPA: https://epa.gov/Superfund/section-4-source-characterization). In the Philippines, it is estimated that approximately 6,000 ha of irrigated land has been affected by irrigation water contaminated by heavy metals in runoff from mine tailings.

Disturbed soils are those that have undergone physical disruption that has resulted in alteration of their primary chemical or physical properties. For example, ex-mining land in Peninsular Malaysia covers approximately 113,700 ha (Chan, 1990) comprising of tin tailings (85.6%) and water bodies (14.4%). The tailings comprise sand and slime (mixture of silt and clay-sized particles) that are physically separated and dumped. Chan (1990) showed that only 4,730 ha (4.2%) of the ex-mining land had been utilised for agriculture and 5.5% for other uses (e.g., housing estates, recreational parks and golf courses). The extent of slime is estimated to cover approximately 10-20% of the ex-mining land and the remaining area is sand (Lim et al., 1981).

In Thailand, the expansion of marine shrimp farming away from the coast into the freshwater areas of the Thai central plain has become an issue for the alienation of good quality agricultural land. The area of land use change area from rice cultivation to brackish water shrimp aquaculture is around 22,455 ha. If unresolved shrimp disease problems occur, shrimp farmers abandon aquaculture completely, leaving saline soils that result in crop failures and land degradation. Vietnam faces a similar problem with the irreversible conversion of paddy rice land to shrimp farms.

Another specific problem associated with some types of mining is exposure of sulfides occurring in mined rock to the air, with resultant oxidation to sulfuric acid ('acid mine drainage') and mobilisation of heavy metals. Whether or not it is possible to rehabilitate contaminated or disturbed land and restore it to a useful function depends on the cause and degree of contamination or disturbance. Heavy metal concentrations for defining 'contaminated soils' in Thailand and Vietnam are documented in Tables 8(a) and 8(b).

Table 8(a) **Threshold concentrations for contaminated soils in Thailand compared with soils in the EU, India and the Netherlands.**

Element	Thai soils for residential and agricultural areas[A]	Thai soils for other purposes[A]	EU soils[B]	Indian soils[B]	Netherlands[C]
	(mg/kg)				
Arsenic (As)	3.9	27	20	-	55
Cadmium (Cd)	37	810	3	3 - 6	12
Copper (Cu)	-	-	140	135 - 270	190
Lead (Pb)	400	750	300	250 - 500	530
Zinc (Zn)	-	-	300	300 - 600	720
Chromium (Cr)	300	640	150	-	380
Mercury (Hg)	23	610	1	-	10

[A]National Environment Board, Ministry of Natural Resources and Environment (2004); [B]Aweng et al. (2011); [C]www.esdat.net/Environmental%20standards/Dutch/annexS_I2000Dutch%20Environmnetal%20Standards.pdf (accessed 28 October, 2016)

Table 8(b) **Threshold concentrations for contaminated soils in Vietnam. [Source: Ministry of Natural Resource & Environment (2015) QCVN 03-MT:2015/BTNMT - National technical regulation on the allowable limits of heavy metals in soils].**

Element	Mean values for agricultural land	Mean values for forestry land	Mean values for residential land	Mean values for industrial land	Mean values for service/market/ trading land
	(mg/kg)				
Arsenic (As)	15	20	15	25	20
Cadmium (Cd)	1.5	3	2	10	5
Copper (Cu)	100	150	100	300	200
Lead (Pb)	70	100	70	300	200
Zinc (Zn)	200	200	200	300	300
Chromium (Cr)	150	200	200	250	250

3.2 Specific soil constraints

Particular soil chemical or physical characteristics can pose challenges to crop growth by restricting uptake of water and nutrients, or restricting/impairing root growth through anaerobic conditions (soil saturation) or elemental toxicities (e.g., aluminium, manganese). Several constraints may occur simultaneously, and amelioration/mitigation options will vary with each constraint. Widely recognised soil constraints are listed in Table 6, together with simple diagnostic indicators.

3.2.1 Acidity

Apart from excessive soil acidity being a consequence of the exposure to air of sulfidic materials in acid sulfate soils, soil acidity can also be intrinsic due to soil-forming processes (e.g., intense weathering) or due to accelerated soil acidification associated with land use. Removal of harvested produce from agricultural land results in the removal of alkaline base elements (potassium, calcium, magnesium, sodium) leading to soil acidification. The rate of acidification is determined by the quantity of removed product, its ash alkalinity, and the pH buffer capacity of the soil (Moody and Aitken, 1997). There is a high risk of accelerated soil acidification caused by product removal in light-textured soils supporting cropping systems with high harvest indices such as hybrid maize or the production of animal fodder. Leaching of nitrate-N due to the overapplication of ammonium-based fertilizers or dung/manure with high ammonium-N content (e.g., chicken manure) is another cause of accelerated soil acidification, but this is only likely to occur under intensive vegetable production in the ASEAN region. It is estimated that acidity affects productivity of 1.7 million ha in Myanmar (Department of Agriculture, Ministry of Agriculture and Irrigation, 2016) and 107 million ha in Indonesia (Ritung et al., 2015).

Table 9 documents the implications and management of soil acidity.

3.2.2 Alkalinity

High pH [pH(1:2.5 water) › 8.0] induces micro-nutrient deficiencies such as copper, zinc, manganese and iron. Calcareous soils (soils with naturally occurring calcium carbonate) and soils impacted by rising saline/sodic watertables may exhibit these deficiencies. Alkaline soils of serpentine origin may show boron toxicity.

Table 9 documents the implications and management of soil alkalinity.

Table 9 **Implications of soil pH and management strategies for maintaining crop productivity. (Source: Moody and Cong, 2008).**

Diagnostic range (soil pH_{water})	Implications	Management
‹4.6	• Soil pH values markedly less than 4: – will be found in peat and acid sulfate soils – may occur in extremely weathered mineral soils of low fertility – may occur in soils of low pH buffer capacity subjected to highly acidifying agricultural practices, such as high application rates of ammonium-based N fertilizers, removal of large amounts of harvested product or mineralisation of nitrate from decomposing leguminous plant residues. • Al or Mn toxicity is probable. • Deficiencies of Mo (because of decreased availability at low pH) and Ca, Mg, and K (due to leaching losses) can occur. • Activity of some soil micro-organisms (especially nitrifiers) is reduced.	To return to a productive state, these soils will require large amount of lime. The rate of liming material required will depend on: the target pH for the amended soil; soil pH buffer capacity; depth of amelioration; soil bulk density; and the neutralising value of the amendment. Farming systems that use highly acid-tolerant species may be used where application of liming materials is not practical. Addition of organic materials to mineral soils may help to ameliorate soil acidity.
4.6 – 5.5	• This pH range denotes significant soil acidification, which can be due to natural processes or to the long-term use of intensive agricultural practices (see above). • Al or Mn toxicity is probable. • Deficiencies of Mo and Ca, Mg, and K can occur, for the reasons given above. • Activity of some soil micro-organisms (especially nitrifiers) is reduced.	Amelioration of soils in this pH range is often necessary if productive yields are to be maintained, and is often economically viable. Amendment rate calculations are outlined above. Use of acid-tolerant species and addition of organic material as outlined above may be employed.

Diagnostic range (soil pH_{water})	Implications	Management
5.6 - 6.5	• At this pH range, optimum growth can be obtained for many acid-tolerant cultivars, providing that adequate amounts of N and P are available. • Mn toxicity may still limit yield in waterlogged soils with high reducible Mn contents.	Amelioration of these soils is economically viable; amendment rates should be calculated as described above; liming strategies should be determined according to the crops being grown.
6.6 - 7.5	• This pH range is optimal for the growth of most plant species. • Mn toxicity may limit yield in waterlogged soils with high reducible Mn contents.	Soils are likely to be productive, providing there are no nutrient deficiencies (e.g. P, N, Zn, Mo) or salinity effects.
7.6 - 8.5	• This pH range is regarded as alkaline. • Zn, Fe and Mn become less available as the pH increases, whereas Mo becomes more available.	Micronutrient deficiencies may be present, particularly where acidic soils have been over-limed.
> 8.6	• At this pH range, soils are strongly alkaline and dominated by Na, Ca and Mg carbonates. • Deficiencies of micronutrients (e.g. Cu, Zn, Fe, Mn), K or P can occur. • B toxicity can exist. • The soil is likely to have a very poor nutritional and structural status.	Only alkaline-tolerant plants will survive, and micronutrients may be required. If soil EC_{se} exceeds 1.9 dS/m, then the soil may be saline and groundwater will need to be lowered. If EC_{se} is less than 0.95 dS/m, then the soil is sodic and will require acidifying; legumes and gypsum may be effective at reducing exchangeable Na.

EC_{se} = electrical conductivity of a saturation extract

3.2.3 Sodicity

Excessive sodium relative to other cations causes soil dispersion with adverse impacts on infiltration of water because the soil disperses on wetting and is hard-setting when dry. Induced nutrient deficiencies (e.g., copper, zinc, manganese and iron) due to the high soil pH are common in crops. This soil characteristic may be caused by soil-forming processes, but can also be the result of rising saline/sodic watertables or inundation with seawater.

3.2.4 Salinity

Similarly to sodicity, salinity can be caused by rising saline watertables or seawater inundation. Because of the high soluble salt concentration in the soil solution, crops suffer severe water stress which causes wilting and possibly death. There is a wide range in the tolerance of crops to salinity, and it may be possible to select a crop that is able to produce yield despite the soil salinity.

It is estimated that there are 6,300 ha of coastal saline-sodic soils in the Lao PDR, 0.5 million ha in the Philippines (Recel, 1989), 0.7 million ha in Thailand, and 1.18 million ha in Vietnam (National Institute for Soils and Fertilizers, 2002). Saline soils occupy 121,000 ha in Myanmar (Department of Agriculture, Ministry of Agriculture and Irrigation, 2016).

3.2.5 Low nutrient retention

Low nutrient cation retention is a consequence of low activity 1:1 clay mineralogy (kaolinite, iron and aluminium hydrous oxides) or sandy texture. The limited capacity for the soil to retain exchangeable Ca, Mg and K is exacerbated in acidic soils because exchangeable acidity (H^+ plus Al^{3+}) is high, further decreasing the proportion of basic cations on the soil's limited cation exchange sites. Crops growing on acidic soils with low cation exchange capacity are more likely to show potassium (K) deficiency than calcium or magnesium deficiency because of the greater crop requirement for K. It is estimated that low nutrient retention is a constraint for 766,000 ha in Myanmar (Department of Agriculture, Ministry of Agriculture and Irrigation, 2016).

3.2.6 High phosphorus fixation

Phosphorus (P) deficiency is a major limitation to crop production in the ASEAN region, and this constraint is exacerbated in soils of high P fixing capacity. The availability of added P is low because it is strongly sorbed onto iron and aluminium oxy-hydroxides in the soil leading to a low soil solution P concentration. It is estimated that high phosphorus fixation is a constraint for 294,000 ha in Myanmar (Department of Agriculture, Ministry of Agriculture and Irrigation, 2016).

3.2.7 Waterlogging

When a soil is waterlogged, there is no air-filled pore space, and oxygen supply to crop roots is therefore severely restricted. Following waterlogging, the soil pH tends to move to a neutral pH 7, with chemically reducing conditions present. Iron and manganese may be reduced to toxic ionic forms (Fe^{2+} and Mn^{2+} respectively), restricting crop growth. Waterlogging can occur in low-lying positions in the landscape, but can also be caused by temporary perched watertables associated with impermeable subsoils (as occur in Plinthosols) or compaction layers; the frequency and duration of temporary waterlogging events will determine the effect on crop growth. If dissolved organic carbon is present in a waterlogged soil, nitrate-N may be lost to the atmosphere by denitrification.

It is estimated that there are 299,000 ha of poorly drained soils in Myanmar (Department of Agriculture, Ministry of Agriculture and Irrigation, 2016), 0.45 million ha in Vietnam (National Institute for Soils and Fertilizers, 2002), and 0.5 million ha in the Philippines (Recel, 1989).

3.2.8 Low plant available water

Water is available for plant uptake between the soil moisture contents of field capacity (or drained upper limit) and permanent wilting point. Sandy soils have low soil water contents at both points and are therefore highly susceptible to drought. Although Ferralsols have a clay loam texture, their clay mineralogy is associated with low water content at field capacity, and these soils are also prone to drought. It is estimated that low plant available water is a constraint for 1.5 million ha in Myanmar (Department of Agriculture, Ministry of Agriculture and Irrigation, 2016).

3.2.9 Hard-setting

Hard-setting characteristics are not only associated with sodic soils but can also be caused by high silt and fine sand contents. Weak aggregate stability leads to slaking when aggregates are immersed in water, and surface crusting (hard - setting) occurs when the soil dries out. These surface crusts reduce seedling emergence, particularly cotyledonous crops such as legumes. Water infiltration is low because of the lack of conduit soil pores.

3.2.10 Compaction

If a soil is tilled or trafficked when its moisture content is higher than its intrinsic plastic limit, smearing of the soil occurs because of its plastic consistency, and a compaction layer is formed. The appearance of the compacted zone appears to be layered ('platy' structure), and it restricts water transmission and root penetration. Temporary perched watertables are formed on top of the compaction layer and lateral sub-surface drainage can occur. Silty soils are particularly susceptible to compaction.

3.2.11 Susceptibility to erosion

On sloping land, surface soils that slake or disperse are highly susceptible to soil loss by erosion. Erosion commences as sheet erosion, but as the runoff water concentrates into preferential flow paths, rills and then gullies form. Soils with sodic subsoils are particularly prone to gully, streambank and tunnel erosion. Slopes as low as 2% can be associated with sheet erosion if the soil is highly erodible. As slope increases, the susceptibility of all soils to erosion greatly increases, and there are large areas of soils in the ASEAN region on slopes greater than 30% [2 million ha in Myanmar (Department of Agriculture, Ministry of Agriculture and Irrigation, 2016); 10.4 million ha in the Philippines (Recel, 1989); 16 million ha in Thailand (Land Development Department, 1990)]. These areas are particularly at risk of erosion and landslip following deforestation.

4. GOOD SOIL MANAGEMENT PRACTICES (GSMP)

4.1 Principles of sound soil management for climate-smart agriculture

Sound soil management is the sustainable use of soil in harmony with agricultural production systems. Importantly, soil management underpins 'climate-smart' agricultural systems which are designed to provide resilience and adaptation to variable climate while mitigating emissions of greenhouse gases (carbon dioxide, nitrous oxide and methane).

From the soil management viewpoint, the key performance indicator for climate-smart agriculture is that the soil is a net neutral or net positive sink for carbon sequestration and is not a source of appreciable nitrous oxide emissions (Paustian et al., 2016). To meet this performance indicator, sound land management must:

- Maximise soil nutrient use efficiency. This can be achieved by adapting nutrient and supplement inputs so that they are appropriate for soil conditions and the soil's productive potential. Applying nutrients in excess of crop demand results in a build-up of nutrients in the soil and high risk of either (i) off-site nutrient movement with impacts on water quality (nitrogen, phosphorus) and/or nitrous oxide emissions (nitrogen), or (ii) soil nutrient imbalances that restrict crop production.
- Control erosion to prevent the loss of valuable soil organic matter and associated nutrients;
- Use integrated nutrient management. This comprises utilising locally available organic materials as nutrient sources in combination with fertilizers, and harnessing the benefit of nitrogen fixation symbiosis;
- Efficiently manage soil water, including effective water harvesting and storage to mitigate drought;
- Incorporate conservation agriculture and organic agriculture principles into the farming system to maintain/improve soil health.

The implementation of these land management principles in ASEAN cropping systems will contribute greatly to mitigating the emission of greenhouse gases from the region (Table 10).

Table 10 **Soil condition and responses for the mitigation of emissions of greenhouse gases for the ASEAN region. (Modified from Paustian et al. 2016)**

Soil/land condition	Mitigation response
Degraded or marginal land	Convert to perennial vegetation
Drained peat soils	Restore to wetland
Acid sulfate soils	Restore watertable; lime; conservation agricultural systems
Sandy and skeletal soils	Convert to perennial vegetation; conservation agricultural systems
Nutrient-depleted soils	Integrated nutrient management including leguminous N-fixation
Excessive cultivation and/or burning of crop residues leading to low organic matter content	Conservation agricultural systems
Low residue crops	Strip cropping/intercropping/relay cropping including perennial crop component and permanent ground cover

4.2 Indigenous knowledge and local wisdom

At local level, farmers often distinguish soil quality (i.e., the intrinsic productive potential of a soil) by such identifiable features as colour, stoniness, texture, and weediness. For example, Lao farmers consider that black soils are fertile, with a high water-holding capacity, and a high earthworm population (as evidenced by the presence of earthworm castings); these soils are associated with high rice yields. Red, white and yellow soils are most commonly described as poor soils because they are considered to be associated with low fertility, poor water retention, and lower yields. It is commonly recognized that grey soils occurring in low positions in the landscape have impaired drainage and are likely to be waterlogged for prolonged periods. The presence of stones is also an indicator of poor soil. Sometimes farmers distinguish soil quality by the associated vegetation, and soils supporting weed species such as *Imperata cylindrica* and *Mimosa invisa* are considered to be poor. While such indicators of soil fertility can be useful at local scale, wider application is often not possible because of differences between regions in soil parent materials and soil forming processes.

4.3 Interaction of good soil and land management practices

Because of the intricate crop/soil interaction, sound soil management outcomes are highly dependent on implementing good land management practices. There are several generic cropping systems that underpin sustainability of the productive capacity of the soil, and these need to be assessed for their applicability at local level.

4.3.1 Cover crops

Cover crops are used primarily to protect the soil from the erosive forces of rainfall, suppress weeds, conserve nutrients from leaching out of the soil system, minimize water loss, improve soil fertility, assist in the control of pests and diseases, add organic matter to the soil, improve soil aeration, promote high water infiltration and provide diversity in the agro-ecosystem. Cover crops are generally planted between cash crop plots (viz. perennial or grass cover crops) or after harvest to rest the land for the next cropping season (viz. annual or biennial cover crops). For example, legumes such as cowpeas and mungbeans are generally used as cover crops after rice to increase soil organic matter and soil nitrogen stocks. Melons, garlic, tomatoes and other short season vegetables are also planted after rice and serve as catch crops to utilize residual fertilizers and moisture. For fruit orchards (e.g., mangoes, citrus), plantation crops (coconut, oil palms, coffee) or vineyards, 'living mulches' such as carabao grass *(Paspalum conjugatum)* or pasture and forage crops are planted between the trees.

Photo 2 ***Arachis pintoi*** **cover crop under dragon fruit at a farm in Malaysia**

4.3.2 Crop rotation

Crop rotation is an orderly manner of planting crops in the same field over a period of four to six cropping seasons. Successive crops are of different genus or species than the previous crop. Crop rotation is an essential component of climate-smart agriculture because it provides resilience and adaptability in the cropping system and maximises benefits to soil health.

The choice of rotation crops is important from the point of view of weed, pest and disease control, maintenance of soil fertility and nutrient balance, and erosion control. Rotation crops are generally grouped into: (1) crops grown for their leaves or flowers such as lettuce and pechay; (2) crops grown for fruits such as tomatoes and eggplant; (3) crops grown for their roots such as carrots and sweet potatoes; and (4) leguminous crops such as beans and peas. The farm is usually divided into four sections and the planting in each section is rotated among the four crop groups. There are many crop rotation sequences practiced in the ASEAN region. For example, vegetables in spring followed by summer rice, maize direct seeded into rice bean residue, and crop cycles of Job's tears/rice bean/upland rice or maize/soybean-winter oats/upland rice (the latter sequences are used in Myanmar).

Mulching is the practice of covering plots with crop residues as soil cover. Crop residues can be either field crop residues after harvest (stubbles, straws, stalks, etc.) or processed residues (bagasse, husks, pulps, peelings, brans, cake etc.). Using decomposable materials as surface covers is inexpensive and has the benefit of potentially increasing soil organic matter. Organic mulches eventually decompose with time and improve soil fertility. Examples of mulching materials used in the ASEAN region include empty fruit bunches from oil palm (Malaysia), rice straw (Vietnam), and seaweed (Vietnam).

Photo 3 **Mulching with rice straw in Malaysia to reduce evaporative losses of soil water and to lower soil surface temperature**

4.3.3 Conservation agricultural practices

The principles of conservation agriculture (CA) are the retention of harvest residues in the field (to recycle nutrients back into the soil, and to reduce soil erosion) and reduced or strategic tillage with controlled traffic [to reduce oxidation of soil organic matter with associated carbon dioxide (a greenhouse gas) emissions and to restrict soil compaction associated with machinery].

In Lao PDR, conservation agricultural principles are applied in Direct-Seeding Mulch-Based Conservation Agriculture (DMC/CA) systems. These systems have developed considerably over the past few decades to the point where the technologies and management practices involved result in financial and soil conservation benefits that clearly offer a viable alternative to traditional farming methods.

However, CA can provide even greater opportunities for livelihood security in addition to the obvious impacts resulting from improved and sustainable yields. These opportunities arise from the potential to incorporate high biodiversity habitats within conservation agriculture schemes. Such 'agro-biodiversity' provides resilience to the effects of climate change and diversity in marketable products.

For example, in the four southern districts of Sayaboury province in Lao PDR, the current cropping systems are based on cash crop production. Maize is the main crop under rain-fed conditions and covers more than 30,000 ha in the region. Three cropping sequences were investigated: (a) Maize monoculture; (b) Two year rotational sequence: maize – rice bean; (c) Two year rotational sequence: maize + *Brachiaria ruziziensis*/ rice bean. Each cropping system had no-till (NT) and conventional tillage (CT) treatments. Independent of soil depth, soil aggregation was greater under no-till conditions and enhanced by crop rotation and the highest dry matter production system (maize + *B. ruziziensis*/rice bean). Soil macrofauna (the number of species and amount of biomass) were increased with no-till and by the cropping sequence. Earthworms increased with no-till and for some cropping sequences. Adapting intensive cropping sequences (high production of above-ground and below-ground biomass combined with a high biodiversity) to no-tillage systems with smallholders is an essential step in achieving long term land sustainability, more reliable yields harvests and higher farm profits against a background of climate change.

Photo 4 **Cassava grown under minimum tillage on sloping land in Vietnam**

4.3.4 Vegetative buffer strips

Vegetative buffer strips are high density rows of plants intended to slow down the velocity of runoff during a rain event, trap soil sediments and pollutants carried by the runoff, and promote water infiltration. The buffer strips are built along the contour to control sheet and rill erosion. In between the buffer strips, farmers plant cash crops. This soil conservation method is also effective for controlling stream bank erosion and reducing river sedimentation. Grasses are generally used for buffer strips, but plant shrubs and under-storey and over-storey trees can also be used. In the ASEAN region, plantings of vetiver grass (*Chrysopogon zizanioides*) or lemon grass (*Cymbopogon* spp.) are often used in buffer strips.

4.3.5 ASEAN case study:

'System of Rice Intensification' in Vietnam

Definition and scope – The System of Rice Intensification (SRI) package was developed from the 'Three Reductions–Three Gains' program for transplanted rice cropping systems in the northern provinces of Vietnam. Traditionally, farmers transplanted rice at a density of 38–50 hill/m^2 and 3–4 plants/hill. Soil was kept flooded for the entire rice season thereby making the soil anaerobic. Excess nitrogen was added, resulting in plants that were weak, with dark green leaves, and less resistant to adverse conditions and pest and disease attack. The rice yield was reduced, while production costs increased, leading to lower profits.

Technical description – The principles of SRI are to:

- Reduce density of transplanting from 30–50 hills/m^2 to 30 hill/m^2, transplanting 12 days after sowing;
- Monitor the amount of applied fertilizer, based on LCC assessment;
- Apply irrigation techniques of Alternate Wetting and Drying (AWD);
- Reduce pesticide usage by following Integrated Pest Management.

Impacts – Application of SRI has assisted in overcoming the limitations of traditional cultivation, by reducing production costs, increasing productivity, lowering production costs and increasing profits. During 2011–2013, SRI was applied in 5 provinces of north Vietnam on a total area of 300 ha. The results (Hach, 2014) showed that:

- Transplanting at low density reduced inputs by 3.8 kg seed/ha and reduced labour costs;
- Applying fertilizers based on crop demand reduced fertilizer application by 53 kg urea + 88.7 kg single super phosphate + 15.5 kg MOP/ha;
- Applying the irrigation method of Alternate Wetting and Drying decreased the volume of applied water by 59%;
- Spraying of pesticides was reduced by 48%.
- Input costs were reduced by 36% for fertilizer, 33% for pesticides, 16% for seed, and water use by 15%;
- Rice grain yield increased by 600 kg/ha (viz. 10%) and profit by 57.5%.

Benefits – The application of SRI management resulted in improved nutrient and water use efficiency, reduced dependence on pesticides, and increased yield (Castillo et al., 2012; Dung et al., 2011). The SRI management practices resulted in a climate–smart cropping system with mitigation of emissions of greenhouse gasses and maintenance of soil fertility and health.

Key references:

Castillo GE, Minh Nguyet Le, Pfeifer K (2012) Oxfam America: Learning from the System of Rice Intensification in Northern Vietnam. (Policy Brief no. 15). In 'Scaling up in agriculture, rural development, and nutrition' (Ed. Johannes Linn, no. 19. June. Washington D.C.: IFPRI).

Dung NT et al. (2011) Simple and effective - SRI and agriculture innovation. System of Rice Intensification website. (28 pp, 1.10MB pdf).

Hach CV (2014) Research Report "Application of Three reductions – Three Gains and SRI technologies for high yield rice in Vietnam in the period of 2011 - 2013".

4.3.6 Acid sulfate soils

Management of acid sulfate soils is intimately linked to the overall management of the site's hydrology. Poor management of the water table will result in increased acidification, poor crop production, environmental degradation and ultimately the loss of the soil resource itself. Three options have been suggested for ASS management in Brunei Darussalam (Fitzpatrick et al., 2008):

- *Avoid disturbance* - Where tests show high levels of sulfidic material the preferred option is not to develop the soil, since the economic and environmental risks of doing so are severe.
- *Minimize disturbance* - Where tests show low levels of sulfidic material, acid sulfate soils can be safely used by careful management of the water table to prevent further oxidation and acid generation. Watertables must be maintained above the level of sulfidic material, and drains should be shallow and carefully levelled to rapidly remove surface water rather than lower the watertable. Irrigation may be necessary during dry spells since root development is always restricted in acid sulfate soils. Raised beds to create a favourable root environment can be constructed with non-sulfidic soil material, or by treating sulfuric layers with lime. Shallow rooted annual crops are preferable to deeper rooted perennial tree crops. Managed oxidation of sulfidic material may be viable provided leachate can be controlled by collecting and liming it, or by flushing it into drains and neutralizing with seawater.
- *Rehabilitation* - Rehabilitation is used where tests show a sulfuric layer or acid water. The basic principles are to curtail sulfide oxidation and to neutralize or leach existing acidity. Re-flooding halts pyrite oxidation but causes reduction of iron, manganese and sulfates which may result in nutrient toxicity for crops. The liming program for an acid sulfate soil needs to neutralize existing acidity as well as potential acidity, and quantities of agricultural lime in excess of 500 t $CaCO_3$/ha for a 50 cm depth interval may be required. Leaching of acid products from the soil is only possible using a water management system that discharges acidic surface water, usually at times of high flow to reduce the environmental impact.

For rice cropping on acid sulfate soils, the recommended amelioration measures are surface soil leaching and drainage, maintain submergence of the sulfidic layer by watertable control, liming, manganese dioxide addition, nitrogen-phosphorus-potassium application including utilization of rock phosphate as a phosphate source and use of acid-tolerant varieties (Attanandana and Vacharotayan, 1986)

Photo 5 **Watergate to control the watertable in an acid sulfate soil area in Malaysia**

4.3.7 ASEAN case study:

'Surjan' system for managing acid sulfate soils in Indonesia

Definition and scope - The Surjan farming system is a traditional farming system developed in Central Java, Indonesia, and is widely used in salinity affected areas, on potential acid sulfate soils, and in tidal swamps. The system consists of parallel ridges and furrows often with sluice gates to control watertable depth in both furrows and cropped ridges.

Technical description - The size of the ridges and furrows vary greatly from place to place and may be from two to fifteen meters wide. The size of the furrow determines the hydrological function of the Surjan. In places where prolonged water inundation occurs, the size of the furrow is increased. Farmers usually construct the Surjan system gradually over a long period of time because continuous digging and stockpiling exposes relatively less weathered subsoil materials which may be a poor substrate for growing plants, particularly if sulfitic. By allowing the stockpiled soil enough time to weather, fertility is built up. During the rainy season excessive water on the ridges is drained to the furrow, removing salinity and acidity from the stockpiled soil.

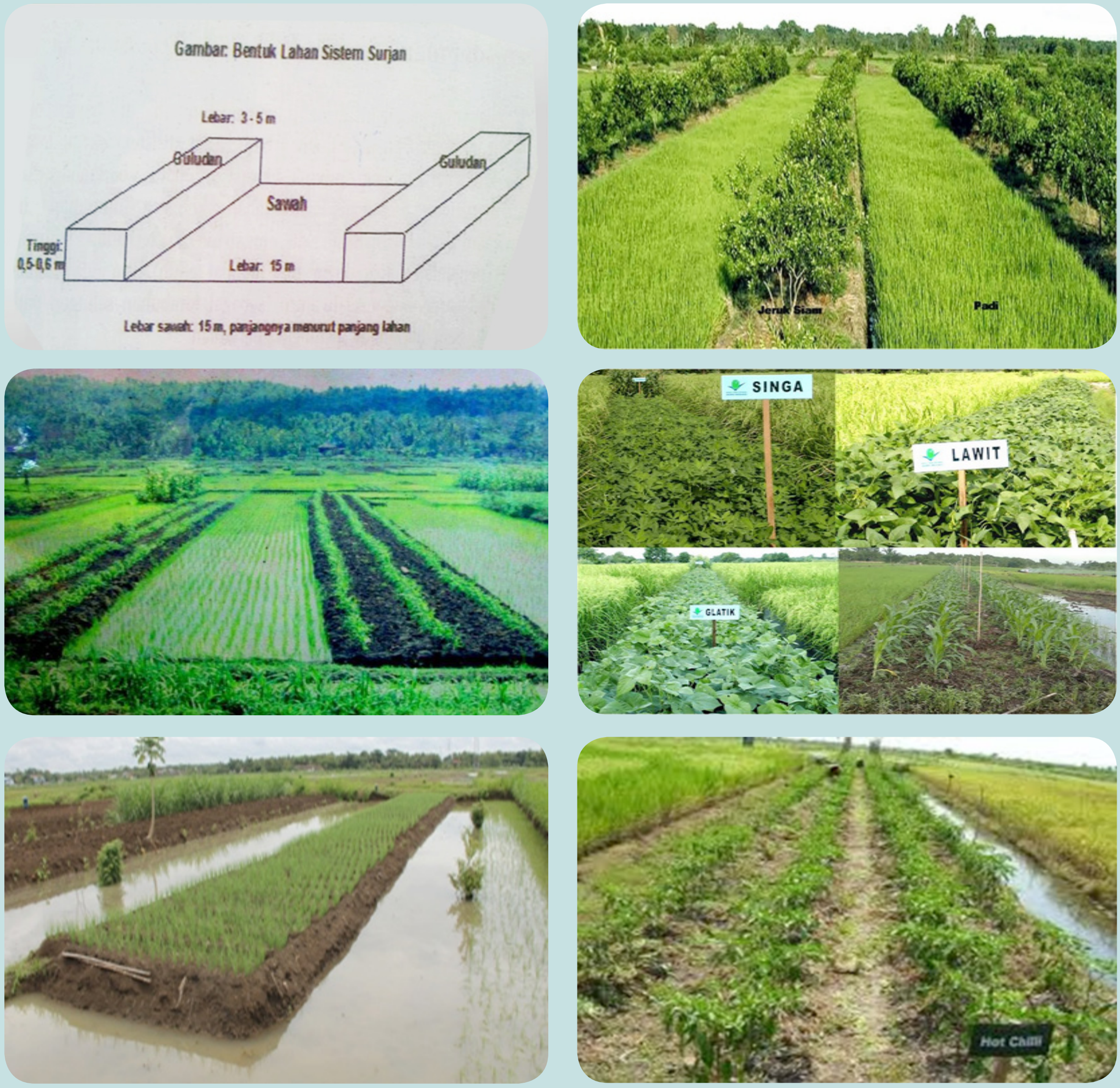
Crops which do not tolerate waterlogging such as maize, soybean, groundnut, cassava and some vegetables are grown on the ridges, whereas the furrows are used for growing wetland rice or aquaculture. If the farmer predicts a low risk of water shortage for rice in the following dry season, then a second rice crop will be grown, otherwise upland crops such as soybeans are planted. Crops on the ridges can be provided with supplementary watering which makes year round production possible. In some places ridges are used for tree crops like coconut, citrus, papaya, jack fruit, clove, and coffee, etc. In this case, the ridges are frequently made individually for each tree. Compared to non-Surjan, the Surjan system increases the cropping index by an average of 227.5%. The Surjan system reduces the risk of complete crop failure and this contributes to the sustainable success of this type of cropping system.

Photo 6 **Cropping configurations in the Surjan system - (a) raised beds for tree crops; (b) raised beds for vegetables, and (c) aquaculture furrows**

a)

b)

c)



Impacts – Comparative economic studies are few. According to one study for the year 1976/77, Surjan farmers obtained an income 2.2 times higher than non-Surjan farmers. However, the level of investment had increased by 134% due to higher input costs associated with crop diversification. Although return to capital decreased from 6.7 to 4.4 (–52%) it remained at a sufficiently high level (Coen Reijntjes, 2011).

Sometimes variations of the Javanese Surjan system are made by making a second higher raised bed on the ridge, giving them a stupa-like shape. Here, the farming system has developed from paddy rice monoculture into a diversified system of paddy rice, dryland crops and fish culture, in which the proportion of rice is gradually reduced. The relative price ratio of rice and coconuts influences the rate of succession. The optimal mix of raised and sunken beds depends on technical factors as well as on farmers' resources and market conditions (Sudaryono and Meindertsma, 1990)

Key references:

Coen Reijntjes: Raised fields for lowland farming. http://www.agriculturesnetwork.org/magazines/global/searching-synergy/lowland-farming#sthash.abt4cbly.dpf – last modified Jun 21, 2011.

Sudaryono, Meindertsma D (1990) The Surjan System: A Sustainable System for Marginal Lands. Malang Research Institute for Food Crops (MARIF). Pp 15.

4.3.8 Peat soils

Peat soils can generally not provide physical support for high biomass perennial crops. These soils can be reclaimed effectively on a sustainable basis by:

- using an appropriate method of peatland clearing; felling and stacking inside the plot and felling and burying are good options compared to felling and burning (Ismail et al., 2007);
- controlled drainage involving a gradual lowering of the ground water table to control subsidence and to prevent spontaneous combustion;
- appropriate nutrient management including liming for excessive acidity and foliar application of micronutrients.

4.3.9 Sandy soils

Because of their intrinsically low nutrient retention and low plant available water capacity, sandy soils can be managed by:

- applying organic amendments such as compost, manure and crop residues. Depending on the characteristics of the amendment and the quantity added, cation exchange capacity and water retention may be increased, and enhanced microbial biomass and activity should improve structure.
- using drip or trickle irrigation to maximise water use efficiency;
- maintaining surface cover by mulching and cover cropping;
- splitting nutrient applications in accordance with crop demand to minimise the risk of off-site nutrient losses.

The need for integrated soil, nutrient, organic matter and water management practices to increase the overall fertility and productive sustainability of these soils is highlighted in a synthesis report on sandy soils management in Vietnam by Ha et al. (2005).

Photo 7 **Beach ridge sandy soil in Malaysia**

4.3.10 Skeletal soils

Because of the restricted rooting depth and tillage difficulty due to gravel/rocks, skeletal soils are best managed by:

- planting fast-growing trees and drought tolerant perennial crops and pastures;
- applying composts, manures or crop residues to improve nutrient and water-holding capacity.

Photo 8 **Skeletal soil in Vietnam cropped with fruit trees, coffee and groundnut**

4.3.11 ASEAN case study:

Remediation of degraded soil at the Khao Cha-Ngum Royal Study Center for Land Degradation in Thailand

Definition and scope – His Majesty the Late King Bhumibol Adulyadej initiated six development study centers in Thailand to address the poverty alleviation of people inhabiting problem soil areas. Sandy textured soils with gravelly laterite or plinthite layers cover at least 69,000 km^2 in Thailand. The Khao Cha-Ngum Royal Study Center for Land Degradation was set up in Ratchaburi Province in 1986 to specifically address the remediation of such soils.

Photo 9 **Skeletal soil at Royal Study Center for Land Degradation prior to remediation**

Technical description – The 'natural way' principles of His Majesty the Late King have been applied by: retaining rain water in local laterite pit storages for irrigation purposes; restoring topsoil fertility by regular addition of tree and crop residues to the soil and incorporating green manure leguminous crops; use of vetiver grass in contour hedgerows and in strips around fruit trees to conserve soil moisture and prevent erosion; scattered planting of Pterocarpus macrocarpus trees amongst regrowth species on sloping land to stabilise re-vegetation of forest areas.

Impact – Rehabilitation practices at the Study Center have taken account of what the local people need to improve their standard of living. This has been facilitated by the formation of local farmer groups to solve their own problems and lay the foundations for self-sufficiency. Local engagement has resulted in diversification of the production systems at the Study Center to include the production of cash crops, vegetable market gardens and animal raising.

Photo 10 **Water storage, vegetable cropping with vetiver hedges, cash cropping and forest after thirty years of remediation**

Key references:

Rojanasoonthon S (2015) Strategic management for poverty alleviation of people inhabiting problem soil areas. *Proceedings of Management of Tropical Sandy Soils for Sustainable Agriculture*, 27 Nov - 2 Dec 2005, Khon Kaen, Thailand. Pp 8 - 15. (FAO: Bangkok, Thailand).

4.3.12 ASEAN case study:

Rehabilitation of sand tailings and tin-mining land in Malaysia

Technical description - Sand tailings have lower concentrations of macronutrients and some of the important trace elements compared to the mineral soils from which they were derived (Ang and Ho, 2002). Sand tailings normally require high input of fertilizers and an efficient irrigation system for agricultural production. The slime (silt plus clay) area requires a good drainage system to reduce water-logging, but it is a better site than sand for growing tree species (Ang and Ho, 2002). The main physical property of sand tailings that requires improvement for growing plants is mechanical impedance. The compaction introduced to the sand tailings is due to the movement of heavy machines during levelling. High mechanical impedance of sand tailings can be overcome by the deep-hole planting technique, followed by an application of organic waste such as empty fruit bunches of oil palm. The average size of the planting hole is 1.5 m length × 1 m width × 1 m depth, and is prepared using an excavator. About 2/3 depth of the hole is back-filled with sand particles. Many studies show that introduction of organic fertilizer either from plant materials or animal wastes to sand tailings will improve soil fertility and also improve soil physical properties.

Impacts - Ex-tin mined land has been rehabilitated successfully for many uses such as agriculture, aquaculture, duck farming and urban uses including housing estates, golf courses and recreation theme parks. Research plantings of various crops on sandy soil with incorporation of decomposed organic matter have produced the yields shown in Table 10.

Table 11 Yields of various crops on mined land

Crops	Yield (t/ha)
Kangkung (*Ipomoea aquatica*)[A]	31.5
Long bean (*Vigna sesquipidalis*)[A]	6.2
Sweet potato (*Ipomoea batatas*)[B]	11-24
Sweet Turnip (*Pachyrhizus erosus*)[B]	25

[A]Sharifudin et al., 1995; [B]Tan et al., 2007.

Key references:

Ang LH, Ho WM (2002) Afforestation of Tin Tailings in Malaysia. Paper presented in 12th International Soil Conservation Organisation Conference, Beijing.

Sharifudin HAH, Shahbuddin MF, Anuar AR, Samy J (1995) Research on Nature Farming Systems in Malaysia: Application of EM Technology. 4th International Conference on Kyusei Nature Farming, June 1995. Paris, France.

Tan SL, Abdul Aziz AM, Zaharah A, Salma O, Khatijah I (2007) Selection of Sweet Potato Clones with High β-Carotene for Processing of Nutritious Food Products. *J. Trop. Agric and Fd. Sc.* 35, 213-220.

4.4 Managing soil constraints

4.4.1 Acidity

- Apply agricultural lime ($CaCO_3$) or dolomite ($CaMgCO_3$). The rate of application depends on the required depth of amelioration because this determines the soil volume being ameliorated. In addition, the following site and product-specific information needs to be known to allow calculation of the appropriate rate of liming material:
  - the target soil pH - the bigger the difference between the unamended soil pH and the amended soil target pH, the greater the amount of amendment required;
  - the pH buffer capacity of the soil; heavy textured soils have a higher pH buffer capacity than light textured soils, and require more amendment to increase their pH by 1 unit (viz. pH buffer capacity is kmol (OH^-)/kg soil/pH unit);
  - the neutralising value of the lime/dolomite;
  - the particle size of the liming material. Incorporation of high rates of good quality lime/dolomite to depth will speed up the rate of neutralisation and ameliorate enough soil volume to provide an adequate root zone.
- Regularly monitor soil pH in the crop root zone to provide early warning of developing subsoil acidity;
- High rates of lime may induce deficiencies of iron, copper and zinc if soil pH increases above pH6.5;
- Minimize removal of crop residues;
- Minimize nitrate leaching;
- Use less acidifying forms of fertilizer.

Photo 11 **Liming to amend soil pH in a peat soil in Malaysia**

4.4.2 Sodicity

Excessive exchangeable and solution sodium (Na) needs to be managed by:

- Application of soluble calcium forms such as gypsum. The required rate of applied calcium can be calculated from the difference between the current exchangeable sodium percentage (ESP) and the target ESP in the amended soil;
- Ponding of freshwater to remove the displaced sodium by leaching.

4.4.3 Salinity

Management of saline soils requires:

- Leaching of soluble salts out of the root zone;
- Replacing exchangeable sodium with exchangeable calcium by adding gypsum;
- Maintaining a cover of surface mulch to reduce evaporation and limit capillary rise of saline water from the watertable;
- In lowland areas, levelling the land to reduce ponding.

4.4.4 Low nutrient retention

Nutrient cation retention can be increased by:

- Addition of materials with high cation exchange capacity (CEC) such as high activity clay minerals (e.g., bentonite) and organic matter;
- Liming to increase CEC in variable charge soils such as those with high content of iron and aluminium sesquioxides (e.g., Ferralsols) and active aluminium (e.g., Andosols). The increase in CEC only lasts as long as the increase in soil pH.
- Split applications of soluble N, K, Ca and Mg fertilizers to reduce the risk of leaching of cations because of low soil CEC;
- Avoiding over-irrigation to reduce the risk of nutrient leaching.

4.4.5 High phosphorus fixation

Management of highly P-fixing soils (such as Ferralsols and Andosols) should aim to:

- Grow low P-demand crops;
- Use minimal rates of water-soluble P fertilizer applied in bands or pockets to reduce fertilizer-soil contact, thereby decreasing the loss of P availability by fixation;
- Apply an initial, low rate, broadcast application of P fertilizer accompanying a banded application to encourage a more uniform crop root distribution;
- Incorporate applications of citrate-soluble P fertilizer such as reactive phosphate rock to provide residual benefit for several years;
- Test soil P test levels regularly to indicate when P application rates can be reduced as soil test levels increase.

4.4.6 Waterlogging

- Artificial drainage is necessary. This may be impractical if the soils occur in low-lying areas or basins with a restricted outlet.
- Mound crop rows to improve drainage in the root zone, thereby minimising the loss of N by denitrification;
- Split N fertilizer application to match crop demand. This will reduce the concentration of nitrate present in the soil at any particular time and thereby minimise N loss by denitrification and runoff.

4.4.7 Low plant available water

- Apply clay materials to increase soil water-holding capacity. Farmers in Thailand and Lao PDR use termite mound material and organic-rich sediment sludge from the bottom of ponds and waterways as soil amendments to increase soil water-holding capacity and also as nutrient sources. Bentonite has been used experimentally as a soil amendment for increasing the water-holding capacity and CEC of sandy soils in Thailand, but it is a high cost product.
- Surface mulch with organic residues to reduce evaporative losses of soil water and assist in increasing water infiltration;
- Use species such as vetiver grass for bunding and terracing. The vertical distribution of the vetiver grass root system is known to access deep soil moisture, allowing the grass to act as a 'living mulch' that does not compete with the accompanying crops for topsoil moisture.
- Use trickle or drip irrigation systems to maintain soil moisture most efficiently;
- Plant drought-tolerant crops.

4.4.8 Hard-setting/dispersion

To reduce the risk of hard-setting:

- Maintain the soil surface in a moist condition and protect from raindrop impact by surface mulching;
- Limit traffic and tillage, particularly when the soil is wetter than its plastic limit.

4.4.9 Compaction

- Improve drainage and aeration in a compacted soil by tillage with rippers, sub-soil implements or chisel ploughs;
- Only undertake tillage when the soil is drier than its plastic limit;
- Use management practices such as minimum tillage, controlled traffic and permanent beds;
- Grow deep-rooted species such as vetiver grass as a biological fix for compaction. Roots will penetrate the compacted layer and dry it out, thereby facilitating soil cracking.

4.4.10 Susceptibility to erosion

The risk of erosion in sloping upland areas can be reduced by the following land management practices:

- Hillside contour ditches with fruit trees planted on the terrace;

Photo 12 **Hillside contour ditches planted with fruit trees in sloping land in Lao PDR**

- Contour alley cropping

Photo 13 **Contour alley cropping of upland rice with a legume crop as the hedgerow in Lao PDR**

- Contour agroforestry with the trees protecting the soil from raindrop impact and stabilising the soil against erosion

Photo 14 **Agroforestry on sloping land in Lao PDR**

- Contour bunding with hedgerow planting (Aung and Yi, 2006). The bunds temporarily capture runoff in porous soil formed by cultivation, thereby preventing sudden run-off at the time of heavy rain and allowing the water to infiltrate into the soil, recharging ground water into downstream and surrounding areas. In the Dry Zone in Myanmar, the contour bunds are practiced in the marginal areas with low productivity, shallow soils and low water infiltration rates and with slope ranging between 1 to 5%. A modification of the bunding is to construct stone bunds in areas with stoniness > 15% and with soil depth 50-100cm. These bunds are constructed as semi-permeable structures, so that runoff velocity is reduced. Bunds should be well stabilized with groundcover and perennial trees/shrubs.

Photo 15 **Contour bunding with vetiver grass in sloping land in Thailand.**

- Sediment storage dams (SS) in upland areas for gully erosion mitigation. These are small earth dams with stabilised spillways constructed across large or medium size gullies. These dams are used for sediment trapping, water collection and diversion and overflow of excess run off. The space behind the SS dam is rapidly converted into fertile and productive fields, in several cases even paddies. Farmers are able to accelerate sedimentation of the dam by re-shaping its borders and levelling the soil.
- Intercropping with lemongrass or vetiver grass.

In a summary of the achievements of the ASIALAND Network on Sloping Land Management, Armada and Correa (2003) stated that the following soil conservation technologies had been validated by network member countries: alley cropping using *Tephrosia candida* and *Coronilla varia* hedgerows (China); hillside ditches and Agroforestry using *Eucalyptus* (China); alley cropping using *Flemingia congesta* hedgerows (Indonesia); cover cropping using *Mucuna munaneae* (Indonesia); crop residue management (Indonesia); agroforestry using teak (Lao PDR); strip cropping with upland rice and soybean (Lao PDR); alley cropping using vetiver and mango as hedgerows (Lao PDR); hillside ditches (Lao PDR); legume cover (Malaysia); rubber inter-cropped with annual and perennial crops (Malaysia); alley cropping with *Gliricida*, napier, banana, sapodilla and cashew as hedgerow crops (Philippines); alley cropping using pigeon pea, *Leucaena*, congo grass, Bahia grass and coffee as hedgerow species (Thailand); hillside ditches (Thailand); agroforestry with coffee and mango (Thailand); alley cropping using *Tephrosia candida* (Vietnam); *Acacia* and pineapple as hedgerows (Vietnam).

4.4.11 ASEAN case study:

Applying 'Sloping Agricultural Land Technology' (SALT) in Myanmar

Definition and scope – 'Sloping Agricultural Land Technology' (SALT) is the use of contour hedgerows and intercropping to improve the quality of sloping agricultural land and to increase crop productivity by minimizing soil erosion and replenishing soil fertility. This is achieved by adopting specific agronomic practices. It is a simple low-cost system for upland resource-poor farmers with few tools, limited capital and little knowledge of advanced agricultural technologies (Watson and Laquihon, 1985). It can increase income generation of upland farmers.

Technical description – The following steps are necessary for applying the SALT technique:

(1) Making the A-frame – The A-frame is used for laying out the contour lines across the slope. Two wooden or bamboo poles about one metre long are nailed as the frame in the shape of a capital letter A. Another one-half metre long pole is tied as the cross bar for the frame. A carpenter's level is tied onto the centre of the crossbar.

(2) Determining the contour line – To prevent soil erosion, the determination of the contour line along the slope needs to be accurate. A spot is marked with a stake. The left leg of the A-frame is placed near that stake. The right leg is swung until the carpenter's level indicates the cross bar is horizontal. Another stake is marked at the spot where the right leg stands. The same levelling process is repeated until one complete contour line is laid out. The distance between the marked contour line and the next one depends on the steepness of slope. Generally the distance between the contour lines is 2-5 metres.

(3) Preparing the land along the contour lines – After determining the contour line on the slope, land preparation can begin. One-metre strips are ploughed and harrowed along the contour lines, using the stakes as a guide.

(4) Planting nitrogen-fixing shrub or tree species – Two furrows are made 0.5 metres apart in the cultivated contour strip. Seeds of a suitable nitrogen-fixing species are planted in each furrow, aiming for a high population stand density.

(5) Planting the perennial crops – The perennial crops can be planted at the same time as the nitrogen-fixing species are sown. They are planted in one contour out of every four. Perennial crops such as banana, cacao, citrus and coffee are suitable for SALT.

(6) Planting the short-duration crops – The short-duration crops are planted between the strips of perennial crops. Suitable short duration crops are maize, ginger, legumes, melon, pineapple, rice, sorghum, and vegetables.

(7) Pruning the nitrogen-fixing trees – Every month the nitrogen-fixing trees are pruned at a height of one metre from the ground. The cut leaves and twigs are spread at the base of the crops. They serve as a source of organic input, minimizing the amount of required chemical fertilizer. To further reduce erosion risk, crop residue branches, rocks and stones are piled at the base of the nitrogen-fixing tree species. These materials will lead to the development of natural green terraces after a few years.

(8) Crop rotation - Short-duration crops should be rotated to maintain crop productivity and soil fertility. Crops such as rice, wheat, maize, potato and cassava are rotated with leguminous crops such as beans, groundnuts and pulses.

Photo 16 **Green hedgerow of pineapple on sloping land in Vietnam**

Development of SALT techniques - Because of its success in the upland region, SALT techniques have been modified into three innovations (Watson and Laquihon, 1985):

- Simple Agro-Livestock Technology (SALT-2) is a small-scale livestock production system with a land use of 40% for agriculture, 40% for livestock and 20% for forestry.
- Sustainable Agro-Forest Land Technology (SALT-3) is a small-scale reforestation technology with a farm area of 40% of agriculture and 60% of forestry.
- Small Agro-Fruit Livelihood Technology (SALT-4) is a system of planting on sloping land with fruit tree area of 75% and food crop area of 25%.

Impacts - The SALT technique can reduce soil losses, reduce the amount of chemical fertilizer used and increase crop yields. Laquihon et al. (1994) reported that this system could reduce soil erosion about 5-8 times as compared to the non-SALT system. The annual rate of soil loss from this system is about 3.4 t/ha/year (Laquihon et al, 1994) whereas the typical annual rate of soil loss in the tropics is 10 to 12 t/ha/year in the tropics (Palmer, 1991). A ten-year economic study done in the Philippines showed that farmers could increase income substantially by using the SALT system. Discussions with upland farmers in Myanmar indicated that positive impacts on soil moisture, percolation and water retention were observed on SALT plots.

Limitations – Because of the requirement to prune and maintain hedgerows, the SALT system is more labour-intensive than traditional farming systems; total labour requirements increased by between 64% and 90% for upland rice and maize crops (Grrity, 1999).

In conclusion, most farmers are unwilling to adopt the SALT technique in their fields without having witnessed benefits themselves due to the high labour costs. They are also wary of possible negative impacts on crop yields caused by the perennial crops shading the short-duration crops. To encourage the adoption of the SALT technique, profitability needs to be proven using demonstration plots in farmers' fields, and some incentives need to be offered such as the provision of improved seed stock and initial fertilizer requirements.

Key references:

Grrity DP (1999). Contour farming based on natural vegetative strips: explaining the scope for increased food crop production on sloping lands in Asia. *Environment, Development and Sustainability* 1, 323–336.

Laquihon WA, Pagbilao MV, Gutteridge RC, Shelton HM (1994). Sloping Agricultural Land Technology (SALT) in the Philippines. In Forage Legumes in Tropical Agriculture, edited by Gutteridge RC, Shelton HM. CAB International Wallingford UK, pp 366–373.

Palmer JJ (1991) The Sloping Agricultural Land Technology (SALT) Experience. Paper presented at The Sloping Agricultural Land Technology (SALT) Workshop, Xavier Institute of Management, Bhubaneswar, Orissa, India.

Watson HR, Laquihon WA (1985) Sloping Agricultural Land Technology (SALT) as developed by the Mindanao Baptist Rural Life Center. Paper presented at the Workshop on Site Protection and Amelioration, Institute of Forest Conservation of the University of the Philippines, Los Banos, Philippines.

5. GOOD NUTRIENT MANAGEMENT PRACTICES (GNMP)

5.1 Integrated plant nutrient management

Integrated plant nutrient management is the balanced use of organic and inorganic forms of nutrients to supply nutrients in synchrony with crop demand. All sources of plant nutrients are utilised including crop residues, green manure crops, manures, composts, and manufactured fertilizers. In addition to supplying nutrients, organic materials may also have beneficial effects on soil structure and water holding capacity, soil chemical properties such as cation exchange capacity, and soil microbial activity.

Integrated nutrient management underpins 'climate-smart' agriculture which comprises resilient, diverse and adaptive multi-cropping systems. Several such cropping systems are used in the ASEAN region, and these systems determine which integrated nutrient management practices are appropriate for the different crops grown and their growing seasons.

- Strip cropping is alternating rows of different crops planted on the contour to reduce the risk of soil erosion. In Lao PDR, maize or upland rice or Job's tears is strip cropped with legumes or groundnut.
- Intercropping is the practice of growing two or more crops together during a cropping season (e.g., Ghosh et al., 2006). This cropping system contributes to agro-biodiversity and ecosystem stability (Zhang and Li, 2006) thereby improving crop resilience to host-specific pests and diseases (Zinsou et al., 2005). Where environmental stress is common, this system provides insurance against crop failure or against high market price fluctuation, resulting to a greater financial stability (Lithourgidis et al., 2011). In Lao PDR, maize, or upland rice is intercropped with *Brachiaria ruziziensis*. Oil palm intercropped with pineapple and coconut intercropped with cocoa is practiced in Malaysia, while pigeon pea plus sesame, cotton, maize, mung bean or groundnut is commonly used in the dry zone of Myanmar.
- Relay cropping or double cropping is where a second crop is planted into the first crop before harvest.
- Crop rotation is the successive cultivation of different crops in a specified order that covers several cropping seasons. In Lao PDR, crop rotation can be a two year cycle (maize direct seeded into rice bean residue), three year cycle (Job's tears/rice bean/upland rice; maize/soybean-winter oats/upland rice) or three to four year cycle (*Brachiaria* spp. for 2-3 years followed by direct seeded upland rice).
- Green manure cropping for improving soil nitrogen and other nutrient availability. For example in Lao PDR, *Sesbania rostrata* and *Aeschynomene afraspera* are used as green manures for rainfed lowland rice cropping systems (Linquist and Sengxua, 2001).

All these cropping systems provide flexible and adaptive responses to seasonal variability and market conditions and are therefore a practical response to climate change.

Photo 17 **Intercropping coconut and cocoa in Malaysia**

Photo 18 **Alley cropping system in Indonesia with *Gliricidia sepium* as the hedge plant**

It is possible to apply 'organic farming' principles to these various cropping systems by using composts and natural soil amendments such as mineral dolomite, gypsum and rock phosphate to supply nutrients. Under an organic farming regime, pest, disease and weed management use biological control measures such as *Trichoderma* for disease control and removal of pests and weeds by manual labour. The 'organic farming' label provides access to a niche market of consumers, and several organic farms in Indonesia, Philippines, Vietnam, and Thailand have achieved certification through the International Foundation for Organic Agriculture (IFOAM) Standard (FiBL-IFOAM survey 2013 in Willer and Lernoud, 2016).

As the world's demand for food increases, the area of arable land can only increase incrementally by expansion onto increasingly constrained soils. It is therefore essential that agricultural production increases. Singapore, with minimal land available for agriculture, has demonstrated an innovative urban response to the demand for green, sustainable crop production. The Sky Greens vertical production system consists of a 9m high tower under a glass roof with vertical rotation of multiple troughs of leafy vegetable plants growing in a soil-based medium. The plants receive uniform sunlight and regulated water and nutrient supply (Khim and Appanah, 2015). While such controlled, protected agricultural systems will increasingly supplement field-produced produce in the future, the need for such systems highlights the critical requirement to protect the productivity and resilience of the world's soil resources.

5.1.1 Crop nutrient requirements

There is variation in the nutrient concentrations required by different crop components to meet internal metabolic requirements, and when multiplied by the typical dry weight of the crop, the quantity of nutrient required for a particular yield also varies. This quantity must be met from soil, amendment and fertilizer sources, and defining it is the first step in using a 'nutrient budget' approach to determine crop nutrient requirements. Table 12 provides the above-ground biomass (shoot/stem/leaves/fruit) nutrient requirements of the priority crops of the ASEAN region.

Table 12 **Nutrient uptake in above-ground biomass and nutrient removed in harvested product (Source: Dierolf et al., 2001).**

Crop	Product	Yield (t/ha)	Total above-ground uptake (kg/ha)						Removal in harvested product (kg/t)					
			N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
Cereals														
Maize hybrid	Grain (LAO)	4.5	115	20	75	9	16	2	15.6 (9.5-35)	2.9 (2-5)	3.8 (3-6)	0.4 (0.3-0.6)	0.9	1.3
Rice improved	Grain (LAO)	4	90	13	108	11	10	4	15.0 (7.9)	2.8 (1.9)	3.8 (2.8)	0.3 (0.4)	1.0 (1.0)	0.8 (0.9)
Root crops														
Cassava	Roots	20	95	15	91	50	15	10	1.7	0.5	2.5	0.4	0.2	0.2

Crop	Product	Yield (t/ha)	Total above-ground uptake (kg/ha)						Removal in harvested product (kg/t)					
			N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
Food legumes														
Groundnut	Grain	2.5	150	13	71	64	21	20	32.0	3.2	4.8	1.6	1.6	1.2
Sesame[A]	Grain (MYN)	(0.5)	(35)	(7)	(9)				(28.3)	(4.8)	(2.4)			
Soybean	Grain	1.5	90	8	36	15	6	10	50.0	4.0	15.3	2.7	2.7	2.0
Vegetables														
Cucumber	Fruit	15	45	7	58	15	6	5	1.7	0.2	1.7	0.3	0.2	0.1
Fruit crops														
Durian	Fruit	12	80	15	116	43	24	20	2.5	0.4	4.2	0.3	0.5	0.3
Mango	Fruit	10	80	9	83	57	36	10	3.0	0.4	3.3	0.7	0.4	0.2
Plantation crops														
Cocoa	Beans	1.5	140	15	158	114	48	10	20.0	4.7	11.3	1.3	2.7	1.3
Coffee	Beans (VNM[B])	1.5 (3.5)	120 (158)	17 (10)	149 (166)	57 (133)	30 (70)	20 (46)	26.7 (45.2)	2.7 (2.9)	28.0 (47.5)	3.3 (3.5)	3.3 (2.9)	4.0 (3.4)
Cash crops														
Sugarcane	Cane	85	110	26	141	57	36	30	1.1	0.2	1.1	0.2	0.3	0.2
Spices														
Chilli	Pods	2.5	160	15	183	36	18	10	24.0	2.8	26.4	2.4	1.2	0.8
Pepper	Pepper-corns	2	180	13	133	29	12	15	30.0	2.5	21.0	2.0	1.0	1.0

[A]Yearly Plant Analysis Data Book (1995-2000), Soil and Plant Analysis Laboratory, Department of Agricultural Research, Yezin, Nay Pyi Taw, Myanmar; [B]Truong Hong, 2015

Soil, amendment and fertilizer sources must meet the above-ground (shoot/stem/leaves/fruit) and below-ground (root/corm/tuber) biomass nutrient requirements of the target harvested yield of the crop irrespective of the amount of nutrient removed at harvest. As an absolute minimum, nutrient inputs must equal nutrient removal in harvested product, assuming that all crop residues are retained on site and not burnt. Because crops are competing with soil microorganisms for nutrients, and the fact that there are always unavoidable nutrient losses by leaching, runoff, gaseous emission (nitrogen) and chemical 'fixation' (phosphorus, and in some soils, potassium), various 'fertilizer recovery efficiency' factors are used in Soil Specific Nutrient Management (see Section 5.2) to calculate nutrient inputs to meet crop removal. Dobermann et al. (2002) reported 'fertilizer recovery efficiencies' of 40 - 60% for N, 20 - 30% for P and 40 - 50% for K for rice systems in Asia.

5.1.2 Practical techniques for assessing and monitoring crop nutrient status

In rice cropping systems, leaf symptoms can be used as an indicator of various nutrient deficiencies/ toxicities. For example, yellowing leaf tips implies nutrient imbalance. Also, sudden leaf shedding can be due to environmental change, exposure to herbicides, pests and diseases, or insufficient nutrient (Lal and Stewart, 2015). Leaf greenness is a visual indicator of the rice plant's N status and the leaf colour chart (LCC) is an easy - to - use and inexpensive diagnostic tool to monitor this. The topmost fully expanded leaf is chosen for leaf colour measurement because it is a good indicator of the overall N status of the crop (Fairhurst et al., 2007).

There is a long established methodology of using the nutrient analysis of 'indicator' leaves of annual and perennial crops to assess their nutrient status. Often leaf samples are taken for a particular crop from several locations where the crop is considered to be adequately supplied with nutrients, and the results of this survey approach are used to establish 'sufficiency' nutrient levels for the crop. This approach has been used for paddy rice, vegetable crops and perennial fruit crops in Brunei Darussalam and Thailand and some vegetables in Singapore (Table 13).

Table 13 **Sufficiency nutrient levels in the leaves of selected vegetables derived from a survey approach. (Source: Arjunan and Varughese, 2010).**

	Baicai (*Brassica* spp.)	Xiao baicai	Bayam (*Amaranthus tricolor*)
N (%)	3.41	4.57	4.55
P (%)	0.63	0.61	0.74
K (%)	4.65	5.52	5.54
Ca (%)	0.85	1.81	1.73
Mg (%)	0.34	0.33	0.97

However, 'sufficiency' levels based on survey data are not definitive, and establishing scientifically robust 'critical' concentrations requires nutrient rate trials to define the plant tissue nutrient concentration versus yield response curve. The 'critical' concentration can then be defined for maximum yield. 'Critical' concentrations of N, P, K, Ca, Mg and S have been tabulated for particular plant tissues sampled at a defined phenological stage of growth in Dierolf et al. (2001).

5.2 Site specific nutrient management

As a minimum requirement, the nutrient management plan for a farmer's field requires information on the rates of nutrients required to produce an economic crop yield. Once these nutrient requirements are known, decisions can then be made on the nutrient sources available to meet the requirements, and fertilizer timing and placement. The availability of nutrient information determines the sophistication and precision of the nutrient management plan. Table 14 documents the various levels of input information required for deciding nutrient management at the field scale.

The most sophisticated and precise nutrient management package is Site-Specific Soil and Nutrient Management (SSNM). SSNM is an adaptive technology package for the sustainable use of soils in harmony with agricultural production systems to suit the needs of particular farm conditions (Fairhurst et al., 2007). This technology package aims to:

- Integrate the use of organic and mineral fertilizer inputs to achieve nutrient use efficiency according to local nutrient availability and cost (i.e., integrated nutrient management);
- minimize off-site nutrient losses by water harvesting, erosion control and conservation agriculture; and
- utilise nitrogen fixation processes to provide some N input.

To maximize the benefit of SSNM, supporting agronomic management practices include using high-quality seeds, optimum planting density, integrated pest management and good crop management. Lastly, SSNM is adaptive and is adjusted to meet local needs using farmer participation.

Table 14 **Input information required by different levels of decision-making for the management of N, P and K.**

Nutrient management technology	Input information	Comments	Example
Generalised	- Crop	Generalised N, P, K requirements	Fruits, vegetables, maize (MYS)
Regional	- Crop - Agro-ecological region	N, P, K requirements based on typical **regional yields**	Paddy rice (BRN)
Region and soil type specific	- Crop - Agro-ecological region - Soil type/texture	N, P, K requirements based on typical **regional yields** and modified according to soil type or soil texture	Paddy rice (LAO); watermelon (MYS); leafy vegetables (THA); mango (THA); maize (VNM); sesame (VNM)
Yield target and soil specific	- Crop target yield - Soil fertility rating	N, P, K requirements based on crop **target yield** and modified according to soil fertility rating based on lab or soil test kit results	Maize (PHL); fruit trees (PHL)
Site and soil specific (SSNM)	- Crop yield gap - Crop nutrient status - Soil fertility analysis	N requirements based on local **yield gap** and LCC (N); P, K requirements based on local **yield gap** and lab or soil test kit results (P, K) that have been calibrated against fertilizer inputs required for a target yield	LCC: Rice (MYN); rice (VNM) Soil Test Kit: Rice (PHL); maize (PHL)

SSNM technology is based on two different approaches to derive a fertilizer requirement; one is based on a nutrient budget approach [e.g., Dobermann et al. (2002) for lowland rice] (Fig. 3), the other on a soil/plant test approach [e.g., Attanandana T, Yost RS (2003) for maize] (Fig. 4).

The nutrient budget approach uses local 'best practice' yield or 80% modelled yield potential as the 'attainable yield' and local nutrient omission trial plots are established in farmers' fields to measure the indigenous nutrient supply, and hence the 'yield gap' that needs to be met by nutrient addition (Fig. 3). These nutrient inputs are calculated from look-up tables of Agronomic Efficiency (kg nutrient uptake/kg yield) and Fertilizer Efficiency Factor (kg nutrient uptake/kg applied nutrient) [see Dobermann et al. (2002)].

The soil/plant test approach identifies the 'attainable yield' in the same way as the nutrient budget approach, but the 'yield gap' is estimated by plant tests [e.g., Leaf Colour Chart (LCC) for N in rice and maize] or soil tests (P, K) that have been calibrated against yield response. Nutrient inputs are then calculated from look-up tables of plant or soil test rating and nutrient requirements [see Fairhurst et al. (2007)].

Figure 3 **Nutrient budget approach to Soil Specific Nutrient Management**

Attainable yield

↓

Crop nutrient requirement (kg/ha)
= yield × (kg nutrient in above-ground biomass / unit yield)

↓

Indigenous soil nutrient supply
= nutrient-limited yield ×
(kg nutrient in above-ground biomass / unit yield)

↓

Nutrient deficit
= Crop nutrient requirement – Indigenous soil nutrient supply

↓

Fertilizer requirement
= Nutrient Deficit / Fertilizer Efficiency Factor

INPUTS

- Local best practice yield
- 80% modelled potential yield
- Table 12
- Nutrient-limited yield from field plots

Figure 4 **Soil/plant test approach to Soil Specific Nutrient Management**

Attainable yield

↓

Actual yield

↓

Yield gap

↓

Indigenous soil nutrient supply
Rating by plant/soil analysis

↓

Fertilizer requirement
N = *f* [LCC rating × Agronomic Efficiency (yield/kg applied N)]
in look-up table
P, K = *f* [Soil test kit rating × Agronomic Efficiency (yield/kg applied P, K)]
in look-up table

INPUTS

- Local best practice yield
- 80% modelled potential yield
- Farmer records
- N-Leaf colour chart rating
- P, K – Soil test kit rating
- Agronomic Efficiency Factor (Rice N: <15 to >25 kg/kgN)

5.2.1 Use of soil test kits to support Site Specific Nutrient Management

To facilitate soil fertility evaluation in remote areas that are removed from ready access to standard soil testing laboratories, rapid soil test kits have been developed for in-field use [e.g., NPK Kasetsart University soil test kit (Thailand: Land Development Department); NPK Bureau of Soil and Water Management soil test kit (Philippines); Paddy, Upland and Fertilizer test kits (Indonesia: Indonesian Soil Research Institute); Soil Test Kit (Myanmar: Department of Agricultural Research). These kits use soil extraction solutions and colorimetric or turbidimetric detection methods to give qualitative (low-medium-high) or semi-quantitative assessments of plant available soil N, P and K. The soil test kit fertility assessments are sometimes used in the soil/plant test approach to Soil Specific Nutrient Management (Fig. 4) to provide nutrient recommendations using crop-specific look-up tables.

Photo 19 **Soil analysis using soil test kit**

In the 'Soils Doctor' program of the Land Development Department in Thailand, a sophisticated 'field lab' assessment of soil pH, soil organic carbon, and available P and K is provided by the measurement of pH and colorimetric determination of extractable P and K. The fertilizer recommendations made by this program are supported by published scientific reports (e.g., Chinabut, 2005) that relate 'field lab' results to field responses by crops to applied fertilizers.

The main advantage of the rapid soil test kits and 'field lab' programs is on-the-spot assessment of soil fertility that allows instantaneous advice to be given to the farmer. This technology is immensely powerful for engaging farmers and building their capacity to make informed decisions about nutrient management. The major disadvantages of this approach are:

- quality assurance/quality control procedures are difficult to implement with the portable, multiple-user test kits , and the quality of the information given to the farmer may be compromised because of this;
- soil test kit ratings may not be supported by rigorous crop response data to support fertilizer recommendations made on the basis of the soil test kit results.

Table 15 summarises the methodologies of rapid soil test kits used in the ASEAN region.

Table 15 **Summary of the methodologies and interpretations of rapid soil test kits used in the ASEAN region.**

Parameter	Extractant	Soil: Extractant	Extraction time	Analytical finish	Detector
pH	THA: water	THA: field survey method	THA: n.a.	THA: indicator	THA: colour chart
	IDN[A]: water	IDN: 1:1	IDN: 5 min	IDN: pH electrode	IDN: pH electrode
	PHL: water	PHL: 1:1	PHL: 5 min	PHL: indicator	PHL: colour chart
Organic C	THA: Walkley Black	THA: 1:2.5	THA: 5 min	THA: Potentiometric titration	THA: colour chart
	IDN: Potassium permanganate	IDN:1:5 by volume	IDN: 30 min	IDN: Permanganate reduction	IDN: colour chart or colorimeter
	PHL: sulfuric acid/dichromate	PHL: 1:0.5	PHL: 30 min	PHL: Dichromate reduction	PHL: colour chart
Extractable P	THA: double acid	THA: 1:4	THA: 5 min	THA: Molybdenum blue	THA: colour chart
	IDN: Dilute acid	IDN: 1:5	IDN: 30 min	IDN: Molybdenum blue	IDN: Test strips or colorimeter
	PHL: ammonium fluoride in HCl	PHL: 1:0.59	PHL: 5 min	PHL: Molybdenum blue	PHL: Test strips
Extractable K	THA: double acid	THA: 1:4	THA: 5 min	THA: cobaltinitrile ppt	THA: colour chart
	IDN: Dilute acid	IDN:1:5	IDN: 30 min	IDN: Tetraphenylborate precipitation	IDN: colorimeter
	PHL: sodium nitrite + Na cobaltinitrite	PHL: 1:1	PHL: 5 min	PHL: cobaltinitrile ppt	PHL: visual observation

[A]IDN: Ministry of Agriculture Regulation (Permentan No. 40/SR. Indonesian Soil Research Institute, Indonesia Agency for Agriculture Research and Development, Ministry of Agriculture

5.2.2 ASEAN case study:

Applying Site Specific Nutrient Management (SSNM) in the ASEAN Region

Definition and scope – Site-specific soil and nutrient management (SSNM) is an adaptive technology package for the sustainable use of soils in harmony with agricultural production systems to suit the needs of particular farm conditions (Fairhurst et al. 2007). The concept has been used to underpin the development of a low-cost decision support system (DSS) that can be applied by maize farmers in Thailand (Attanandana and Yost, 2003). The maize DSS uses crop modelling to evaluate recommendations for nutrient management at specific sites, simplified soil information to identify soil series, and a simple soil test kit to assess soil nutrient status in the field.

Dissemination of the DSS was modified to increase farmer empowerment by identifying and empowering farmer leaders (Attanandana et al., 2004). The *SimRice* DSS was released in 2005 to aid decision-making by providing on-site calculations of the nitrogen, phosphorus and potassium (NPK) fertilizer recommendations using soil series identification and soil test kit results. DSSs based on the same principles have been developed for maize (*SimCorn*) (Attanandana et al., 2006) and sugarcane (*SimCane*).

Based on data presented by Pasuquin et al. (2014), the average grain yield increases for maize were 1.0 t/ha (+ 13%) over the current farmer's fertilizer practice (FFP) in the same cropping system across 3 countries (Indonesia, Philippines, and Vietnam). Likewise, SSNM on rice was launched in Indonesia in January 2011 and was updated in February 2015 as a rice agro-advisory service for Indonesia. Results showed an increase in rice production over farmer's practice of 0.1 t/ha in Java, 0.7 t/ha outside Java (irrigated), and 0.4 t/ha outside Java (rain-fed) (Buresh, 2016).

Technical description – The processes applied in SSNM for maize (*Zea mays*) are outlined below (Witt et al., 2009):

Step 1: *Establish an attainable yield level* – Maize yields are location - and season - specific and determined by climate, variety, and crop management. The attainable yield for a given location and season is estimated from farmers' fields where good crop management was practiced and nutrients were not limiting yield. The quantities of nutrients taken up by a maize crop are directly related to yield. The attainable yield level therefore indicates the total quantities of nutrients required by the crop.

Step 2: *Effectively use existing nutrients* – The SSNM approach promotes the optimal use of existing (indigenous) nutrients coming from the soil, organic amendments, crop residues, manure, and irrigation water. The uptake of a nutrient from indigenous sources can be estimated from the nutrient-limited yield, which is the grain yield for a crop not fertilized with the nutrient of interest but fertilized with other nutrients to ensure they do not limit yield.

Step 3: *Apply fertilizer to fill the deficit between crop needs and intrinsic supply* – Fertilizer N, P, and K are applied to supplement the nutrients from indigenous sources and achieve the yield target (= 'attainable yield'). The quantity of required fertilizer is determined by the deficit between the crop's total needs for nutrients-as determined by the attainable yield level-and the supply of these nutrients from indigenous sources-as determined by the quantities in the nutrient-limited yield. Because not all of the nutrients applied in the fertilizers are captured by the crop, 'fertilizer efficiency' factors are used to calculate nutrient inputs to meet crop requirements.

Impacts - The SSNM conceptual approach in the Sim-series of DSSs was simplified, and the dissemination process was modified to increase farmer empowerment by identifying and empowering farmer leaders. These two strategies of simplifying the agricultural technology and building farmer capacity resulted in higher maize yields and profit by the farmers. Increased self-reliance, a better standard of living, more knowledge of crop production, soil improvement and networking of the farmer associations were all observed (Attanandana et al., 2008).

Key references:

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Attanandana T, Phonphoen A, Pinchongskuldit A, Yost RS (2006) SimCorn-A Software Designed to Support Site-Specific Nutrient Management for Farmers of Small Parcels in the Tropics. In 'Computers in Agriculture and Natural Resources' (Eds Zazueta JXF, Ninomiya S, Schiefer G) (American Society of Agricultural and Biological Engineers: Orlando, Florida).

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Fairhurst T, Witt C, Buresh R, Dobermann A (2007) Rice: A Practical Guide to Nutrient Management.2nd ed. (International Rice Research Institute, International Plant Nutrition Institute, and International Potash Institute: Philippines).

Pasuquin JM, Pampolino MF, Witt C, Dobermann A, Oberthur T, Fisher MJ, Inubushi K (2014) Closing yield gaps in maize production in Southeast Asia through site-specific nutrient management. *Field Crops Research* 156, 219-230.

Witt C, Pasuquin JM, Pampolino MF, Buresh RJ, Dobermann A (2009) A manual for the development and participatory evaluation of site-specific nutrient management for maize in tropical, favorable environments. Draft 05, 28 January 2009. (International Plant Nutrition Institute: Penang, Malaysia).

5.3 Source and form of nutrients (inorganic, organic)

Both organic and inorganic fertilizers provide the plant with nutrients essential to growth, yield and quality of product. Inorganic manufactured fertilizer has a high nutrient content of known composition. Organic fertilizers contain organic carbon and can improve soil fertility and physical properties of soils; their nutrient content and composition is often unknown and/or variable. Table 16 describes the availability of nutrients in various nutrient sources.

The use of organic and inorganic fertilizers must comply with Good Agricultural Practices (GAP). These are 'practices that address environmental, economic and social sustainability for on-farm processes, and result in safe and quality food and non-food agricultural products' (FAO, 2003). ASEAN GAP standards apply to: site history and management; planting material; fertilizers and soil additives; water; agrichemicals; harvesting and handling produce; traceability and recall; training; documents and records; and review of practices.

Table 16 **Fertilizer types, forms and nutrient bioavailability**

Fertilizer type	Fertilizer form	Nutrient bioavailability
Organic fertilizers	Animal dung	Release of nitrogen and phosphorus into inorganic forms for crop uptake depends on mineralisation of the organic C in the dung and its C:N:P ratio. If this ratio is greater than about 100:10:1 with reference to the carbon component then temporary immobilisation of N and/or P is possible. Dung not only acts as a source of plant nutrients but, through the addition of organic carbon, also helps to improve physical properties such as soil tilth, structure, aeration and water holding capacity. However, animal dung may pose a risk to food safety because of pathogens, and reference must be made to food safety standards in the ASEAN GAP document (FAO, 2003) to ensure the use of animal dung does not breach these standards.
	Compost	Plant residues remaining after harvest can be used for making compost. Compost is any product that has undergone controlled biological decomposition of organic material of plant or animal origin that has been sanitized through the generation of heat and stabilized to the point that it is beneficial to plant growth. Compost provides many nutrients that plants need in small amounts, such as boron. Matured compost should not be susceptible to the temporary N/P immobilisation that can be observed with manures/green manures.
	Green manure	Green manure crops are grown to maintain or improve the soil organic matter and N content of soil (Carucci, 2001). Legume crops (e.g., *Crotalaria juncea, Sesbania rostrate, Vigna unguiculata, Canavalia ensiformis*) are grown and incorporated into the soil before they reach maturity. As the low C:N ratio legume material decomposes, it provides nutrients and may improve soil structure because of its organic carbon content.

Fertilizer type	Fertilizer form	Nutrient bioavailability
Inorganic fertilizers	Single form	Fertilizers are manufactured as specific compounds such as urea (46 - 0 - 0), di-ammonium phosphate (DAP) (18 - 48 - 0), single/triple superphosphate (0 - 16 - 0/0 - 45 - 0) and potassium chloride (MOP) (0 - 0 - 60). Nutrients are immediately bioavailable because they are in water soluble form.
	Bulk blended/ physical mixture	Matching bulk blends of specific granulated fertilizers to the specific nutrient requirements of the crop helps to optimize the use of the applied nutrients and protects the environment through balanced nutrition.
	Compound	Compound fertilizers are multiple nutrient compounds combined by chemical processing into individual fertilizer granules to ensure uniformity of nutrient ratios.
	Liquid	Foliar nutrient application of specific compounds is useful when soil conditions restrict nutrient availability to roots, or when a nutrient supplement is required. A dilute solution of the nutrient must be able to supply the amount needed by the crop.
Bio-fertilizers	Biofertilizer	Biofertilizers comprise active populations of specific microorganisms that can: fix atmospheric nitrogen gas into organic forms; solubilize phosphate and potassium soil minerals; or enhance nutrient absorption by plant roots. In Thailand, 4 types of biofertilizer are commercially available: N-fixing rhizobium for leguminous crops; plant growth promoting rhizobacteria (PGPR) for rice, sugar cane, maize and cassava; phosphate solubilizing bacteria for maize; mycorrhiza for rubber, oil palm, orange, asparagus, and fruits. In the Philippines, the bio-fertilizer Bio-N is applied to rice and maize to reduce manufactured fertilizer inputs by 50%. The active microorganism is *Azospirillum* in a sterile soil medium.

Chemical contamination of fresh produce can be caused by the presence of heavy metals (particularly cadmium) in low grade fertilizers and soil additives such as gypsum, animal dung, biosolids and composts. Biological contamination of fresh produce can occur through the use of organic products. Untreated animal dung or improperly composted materials can contain high levels of pathogenic microorganisms. Contamination can occur through direct contact of the organic product with the edible part of the crop during soil or foliar application or indirectly through contamination of soil or water.

5.4 Sound practices for utilising inorganic, organic and bio-fertilizers

As discussed in Section 5.1, integrated nutrient management is the balanced use of organic and inorganic forms of nutrients to supply nutrients in synchrony with crop demand. These nutrient sources include manufactured inorganic fertilizers, crop residues, green manure crops, manures and composts.

Nutrients in inorganic fertilizers can generally be considered to be immediately bioavailable, but there are exceptions. Phosphate in rock phosphate and fused magnesium phosphate may not be immediately available, and it is necessary to discriminate between immediately available water-soluble P and the more slowly available (depending on soil conditions such as pH) citrate-soluble P. Likewise, it is generally assumed that urea $[CO(NH_2)_2]$ undergoes rapid hydrolysis to produce ammonium-N. However, the urease enzyme is required for this hydrolysis and in some soils, urease activity is inhibited (or may even be eliminated by commercially available urease inhibitors), and this delays the conversion of urea to ammonium-N.

The bioavailability of nutrients in organic fertilizers such as crop residues and animal dung is extremely varied and cannot be easily predicted. Total N, P and K contents give no indication of the rate of release of these nutrients into bioavailable forms, and the total organic carbon (C) content of the organic fertilizer does not discriminate between the easily decomposable organic carbon found in legume residues and the more recalcitrant organic carbon found in char products. While a C:N ratio of < 24 suggests that N mineralisation may occur as the organic material breaks down, there is no guarantee of how much of the total N will mineralise, and in what timeframe. It is therefore essential that the nutrient analysis of the organic fertilizer is known and that farmer is guided by local experience and technical advice when deciding what contribution, and over what timeframe, these products can provide available nutrients to the crop. Table 17 gives typical nutrient levels and C:N ratios of a range of organic amendments.

Table 17 **Typical nutrient content and C:N ratios of selected organic amendments**

Materials	Nutrient (%)[A]			
	%N	%P	%K	C/N[B]
Cow manure	1.10	0.40	1.60	18
Pig manure	1.30	2.40	1.00	13
Chicken manure	2.42	6.29	2.11	
Duck manure	1.02	1.84	0.52	21
Bat manure	1.54	14.28	0.60	
Rice straw	0.59	0.08	1.72	40-89
Rice husk (15% SiO_2)	0.46	0.26	0.70	111-152

Materials	Nutrient (%)[A]			
	%N	%P	%K	C/N[B]
Water hyacinth (*Eichhornia crassipes*)	1.55	0.46	0.49	24 - 60
Cowpea (*Vigna unguiculata*)	2.05	0.22	3.20	
Maize stem	0.71	0.11	1.38	55
Maize cob	1.78	0.25	1.53	
Cassava stem	1.23	0.24	1.23	29
Vegetable residues	2.5 - 4.0			11 - 12

[A]Meunchang et al. (2005); [B]Golueke (1982)

6. STANDARDS AND REGULATIONS FOR FERTILIZERS AND SUPPLEMENTS IN THE ASEAN REGION

For consumer protection, ASEAN Member States have minimum standards and regulations for the composition, labelling, storage, transport and handling of materials that claim to be fertilizers or bio-input products. The aim is to protect the consumer from purchasing unwanted components in a fertilizer (e.g., fillers), to protect public health from contaminants and harmful biological agents, and to maximise product efficacy (e.g., shelf-life). Table 18 lists the agencies responsible in the ASEAN Member States for registering fertilizers, organic fertilizers and bio-fertilizers.

Fertilizers are purchased to supply nutrients and therefore it is important that the end-user understands the bioavailability of the nutrients, or the plant production efficacy of the biological constituents, in the fertilizers. The difference in bioavailability of water soluble versus citrate soluble P in P fertilizers is adequate reason for inorganic P fertilizers to be required to indicate the contents of these two forms of P on the label.

The efficacy of inorganic soil amendments such as agricultural lime, dolomite and gypsum is not only dependent on their carbonate content (agricultural lime/dolomite), but also on their water content, neutralizing value (agricultural lime/dolomite), particle size and solubility (gypsum). The neutralizing value (NV) of a liming material is its ability to neutralize acidity when compared to pure calcium carbonate which has NV 100%. A good quality agricultural lime has NV > 70%, the proportion of fine material (< 0.25mm) > 40%, and a low moisture content. It would greatly assist the consumer for the particle size and NV of a product being sold as a soil amendment to be specified on the label. Currently, this information is not required to be displayed in the ASEAN region.

Table 18. **Agencies responsible for registering manufactured fertilizers, organic fertilizers and bio-fertilizers in ASEAN Member States**

ASEAN Member State	Inorganic fertilizer	Organic fertilizer/ biofertilizer
Brunei Darussalam	No registration currently required.	No registration currently required.
Cambodia	Dept. of Legislation, Ministry of Agriculture, Forestry and Fisheries	Dept. of Legislation, Ministry of Agriculture, Forestry and Fisheries
Indonesia	Ministry of Agriculture (Directorate General of Infrastructure and Facilities of Agriculture)	Ministry of Agriculture (Directorate General of Infrastructure and Facilities of Agriculture)
Lao PDR	Ministry of Agriculture and Forestry	Ministry of Agriculture and Forestry

ASEAN Member State	Inorganic fertilizer	Organic fertilizer/ biofertilizer
Malaysia	No registration currently required.	No registration currently required. Imported and exported fertilizer must satisfy import or export requirements.
Myanmar	Dept. of Agriculture, Ministry of Agriculture, Livestock and Irrigation	Dept. of Agriculture, Ministry of Agriculture, Livestock and Irrigation
Philippines	Fertilizer and Pesticide Authority	Bureau of Agriculture and Fishery Standards
Singapore	Imported fertilizer must satisfy import requirements	No registration currently required.
Thailand	Dept. of Agriculture	Dept. of Agriculture
Vietnam	Ministry of Agriculture	Ministry of Agriculture

While quality standards exist for total organic C, N, P and K contents and the C:N ratios of organic fertilizers and mature composts (Table 19), as discussed in Section 5.4 these values give no indication of the rate of release of nutrients into bioavailable forms.

Biofertilizers are microbial cultures of plant productivity enhancing or enabling organisms, and the minimum labelling requirements are therefore:

- Product manufacturer and contact details;
- Scientific names and number of all active microorganisms per unit weight or volume of the product;
- General description of the product media;
- Expected shelf-life of the product;
- Storage and handling conditions of the product for maximum longevity of the microbial activity and minimal risk to human/animal health;
- Recommended application rates and application methods;
- If claims are made that using the product will reduce the amounts of required nutrients then these claims should be supported by valid scientific data. Testimonials have no scientific validity.

The standards in terms of constituents that must be met by biofertilizers and mature composts in the ASEAN region are presented in Table 19.

Table 19 **Standards for the properties of organic fertilizers and mature compost in ASEAN countries**

	IDN[A]	LAO	MMR	MYS[B]	PHL[C]	THA Mature Compost	VNM[D]
Particle size		≥ 12.5 × 12.5 mm		> 90% not less than declared particle size		≥ 12.5 × 12.5 mm	
Moisture content	15 - 25%	< 30%		< 30%	30 - 35%	≤ 35%	
Inert material by weight (stones/sand)	≤ 2%	< 2%				< 2%	
Inert contaminants by weight (plastic/metals)	≤ 2%	none				< 0.01%	
pH (H_2O)	4.0 - 9.0	6.5 - 8.5		5.0-8.0		5.5 - 8.5	
C:N	15 - 25	< 20:1	< 20:1	< 25:1	12:1 - 20:1	< 20:1	< 12:1
EC (Electrical Conductivity)		< 4 dS/m				≤ 3.5 dS/m	
Organic matter (OM)	≥ 26%	> 30%	> 20%	> 50%	≥ 20%	> 35%	> 20%
Organic carbon (OC)	≥ 15%	> 17.4%					
Total N	$N + P_2O_5 + K_2O$ > 4%	> 1.5%		> 1.5%	$N + P_2O_5 + K_2O$ = 5 - 7%	≥ 1.0%	> 2%
Total P_2O_5		> 1.0%				≥ 0.5%	
Total K_2O		> 1.5%				≥ 0.5%	
Arsenic (As)	< 10 mg/kg	< 10 mg/kg		< 50 mg/kg	< 5 mg/kg	≤ 50 mg/kg	< 10 mg/kg
Cadmium (Cd)	< 2 mg/kg	< 5 mg/kg		< 5 mg/kg	< 5 mg/kg	≤ 5 mg/kg	< 5 mg/kg
Chromium (Cr)		< 50 mg/kg		< 200 mg/kg	< 150 mg/kg	≤ 300 mg/kg	
Copper (Cu)		< 300 mg/kg			< 300 mg/kg	≤ 500 mg/kg	< 200 mg/kg
Zinc (Zn)	< 5000 mg/kg				< 5 mg/kg		
Lead (Pb)	< 50 mg/kg	< 500 mg/kg		< 300 mg/kg	< 250 mg/kg	≤ 500 mg/kg	
Nickel (Ni)				< 150 mg/kg	< 50 mg/kg		
Mercury (Hg)	< 1 mg/kg			< 2 mg/kg	< 2 mg/kg	≤ 2 mg/kg	< 2 mg/kg
Complete decomposition						≥ 80%	
Faecal Streptococci					< 5 × 10^2 CFU/g		
Total coliforms					< 5 × 10^2 CFU/g		
Salmonella spp.					nil		
Infective parasites					nil		
E. coli	< 100 MPN/g			< 10 CFU/g			
Pseudomonas aeruginosa				< 10 CFU/g			
Staphyococcus aureus	15 - 25%			< 10 CFU/g			
Salmonella spp.	< 100 MPN/g			Absent			

[A]70/Permentan/SR.140/10/2011: Minimum Technical Requirements For Solid Organic Fertilizer, INDONESIA; [B]MS 1517 : 2012 Organic Fertilizers - Specification (First Revision), MALAYSIA; [C]ICS 65.080, PNS/BAFS 183:2016, Bureau of Agriculture and Fisheries Standards, PHILIPPINES; [D]Annex VIII of Circular No. 41/2014/TT-BNNPTNT dated November 13, 2014 of The Minister of Agriculture and Rural Development, VIETNAM

7. GENERAL CONSIDERATIONS IMPACTING THE GUIDELINES

7.1 Quality assurance and quality control

The Guidelines on Soil and Nutrient Management have several components that are dependent on chemical analyses for:

- assessing compliance with fertilizer and bio-input quality standards;
- determining soil and plant nutrient concentrations;
- undertaking rapid soil and plant tests using field test kits.

These dependencies require accurate and reproducible results that are independent of the laboratory/ equipment providing the results. The role of quality assurance/quality control processes and procedures is to provide this assurance by ensuring that:

- standard operating procedures are documented and followed for each analytical method;
- chain of custody processes are followed to ensure sample integrity and confidentiality of results;
- active quality control procedures/processes are documented and implemented;
- the testing laboratory participates in an ISO/IEC 17025 accreditation scheme to demonstrate laboratory quality assurance;
- the testing laboratory participates in an inter-laboratory proficiency testing programme to demonstrate robustness of test results (e.g., SEALNet – Thailand; WEPAL – Netherlands).

7.2 Training, capacity building and advocacy of soil and nutrient management

The Guidelines for Soil and Nutrient Management will remain on book shelves unless comprehensive programs involving training and capacity building are undertaken with end-user groups, and government agencies are vocal and effective advocates for their implementation. There are lessons to be learnt from attempts to implement technology packages such as Soil Specific Nutrient Management, and Attanandana et al. (2008) summarised the following critical factors for successful implementation of a technology package:

- Identification and empowerment of end-user group 'champion advocates';
- Focus on self-reliance, participatory and interactive learning;
- Networking within end-user groups to encourage sharing and learning;
- Active local testing, application and 'customisation' of package principles;
- Local availability of key resource materials;
- Continuous improvement in the package through feedback, monitoring and evaluation.

In addition, it is essential for training, capacity building and advocacy to complement, and respond to, the 'Vientiane Declaration on Enhancing Gender Perspective and ASEAN Woman's Partnership for Environmental Sustainability' adopted by ASEAN Leaders on 19th October 2012. Gender perspectives need to be incorporated and promoted in the design and planning of relevant technologies and practices, interventions, measures and policies to ensure men and women have equal opportunities in terms of participating and benefitting from the implementation of options and recommended practices. Appropriate interventions need to consider the preferences and particular needs, priorities, and reality of different groups of men and women, and adequately address these in the design and implementation of technologies and practices. This will encourage/accelerate adoption of technology and provide equal opportunities for men and women to uptake new appropriate climate resilience technology and practices. Specific technology and practices that are gender responsive can lead to improvements in the lives of smallholder farmers, as well as deliver more sustainable results and impact.

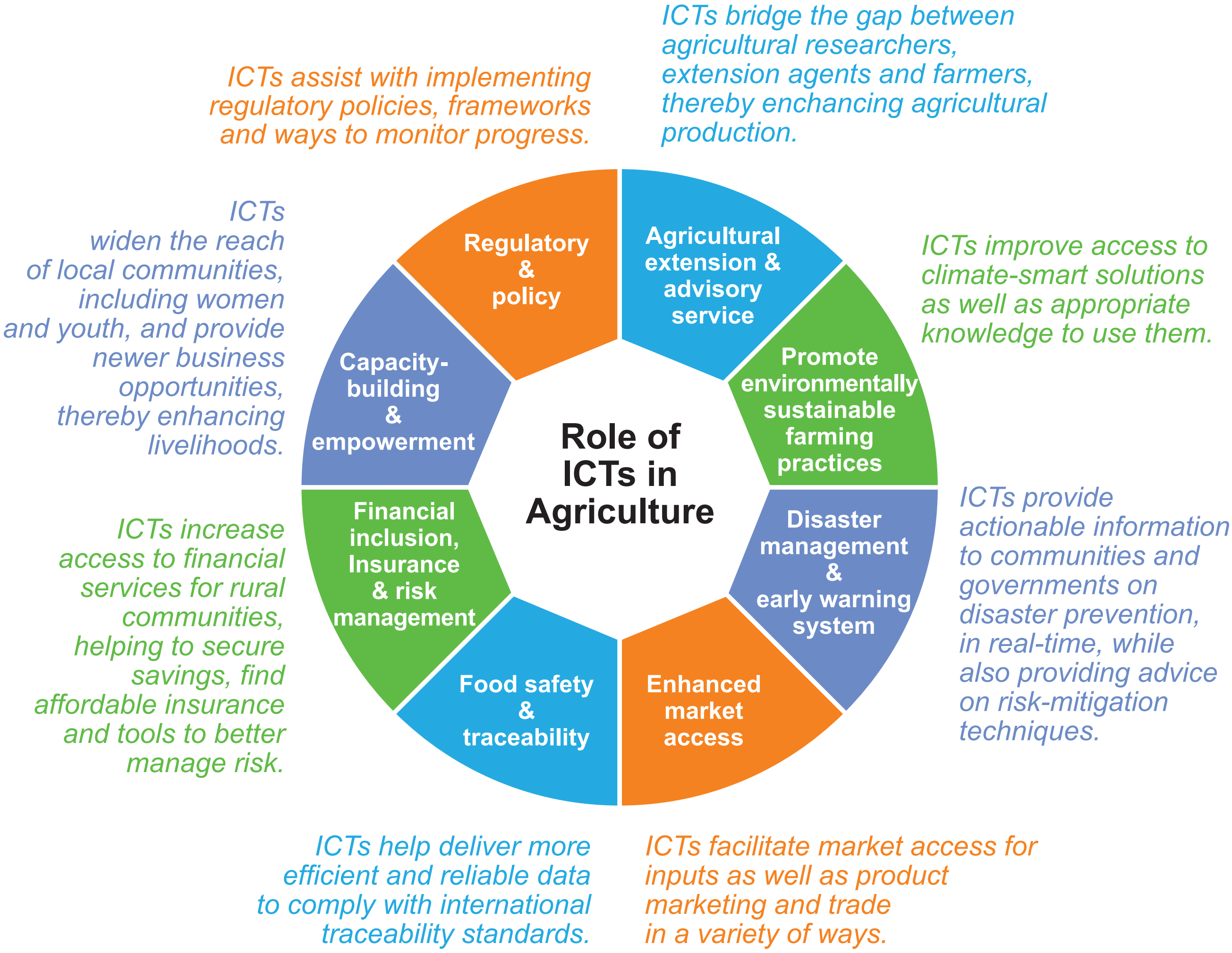
It is essential that the Guidelines are accompanied by a regional implementation plan.

7.3 Role of Integrated Communication Technology in Soil and Nutrient Management

Soil and nutrient management (SNM) is but one component of the e-Agriculture approach required for sustainable and resilient climate-smart agricultural systems (Fig. 5); SNM interacts intimately with water and pest management and an integrated communication technology is fundamental to support this interaction.

E-Agriculture initiatives such as the 'Direct2Farm' Program of CABI aim to have an Integrated Communication Technology (ICT) – based knowledge service that 'helps farmers to acquire new skills, learn new technology, discover new business opportunities and improve livelihoods' (http://direct2farm.org/: accessed 29 October 2016). This ICT knowledge service uses a WiFi/3G tablet with apps to deliver information and collect data for e-transmission to resource hubs. These resource hubs use expert networks and collaborators to respond to enquiries via SMSs. Enquiries are saved to a database which becomes a resource base for later searches and export.

Figure 5 **Role of ICT in agriculture. Source: FAO - ITU (2016)**



Source: FAO, ITU

Soil and nutrient management is ideally suited to ICT delivery for: (a) problem-solving using remote diagnostic services; (b) capacity-building of farmers through the provision of training resources; and (c) facilitating communication and collaboration between farmers, extensionists, researchers, and policy-makers. The primary pre-requisite for an ICT approach to SLM already exists because the key site and soil properties in Table 20 are all amenable to remote field capture by the GPS, camera, and text facilities of Smartphones, and could be transmitted to a regional resource hub of scientists and extensionists for interpretation and advice.

Table 20 **Key site and soil properties to assess soil productivity and soil constraints (Moody and Cong, 2002). Asterisk identifies site/soil properties suitable for monitoring.**

Site	Location Altitude Landform Landscape position Slope Vegetation* Current land use* Surface condition* Evidence of erosion* Occurrence and redox status of a sulfidic layer in the subsoil*
Soil	Texture Colour Structure Aggregate stability (slaking/dispersion)* Moist consistence Mottles Compaction* Root depth* Gravel Permeability class Drainage class Field measurement of pH* Field measurement of EC* Field measurement of organic carbon*

8. LINKAGES BETWEEN GUIDELINES AND USER REQUIREMENTS

Table 2 identified the information required by the various user groups from the Guidelines to meet their needs. User motivations and required information are reproduced in Table 21 with linkages to the Guidelines identified. Table 20 identifies the key site and soil attributes that can be used to identify soil constraints and also the attributes that are suitable for monitoring soil condition over time.

Table 21 **Motivations and information required by end users reproduced from Table 2, with linkages to Guidelines documented**

Motivation	Required information	Linkage to Guidelines
- Food security	Methodology and interpretive guidelines for categorising and monitoring key soil properties.	Section 2.2- Use of the Fertility Capability Classification (FCC) to identify soil constraints from key soil properties and provide options for mitigation. Key soil properties for monitoring identified in Table 20.
- Climate change	Nutrient requirements of key crops in water use efficient/climate change resilient cropping systems.	Section 5.1 Crop nutrient requirements linked with Section 4.1 Climate-smart agricultural systems.
- Alienation of Good Quality Agricultural Land (GQAL)	Methodology and interpretive guidelines for soil properties considered to be essential for productive arable soils.	Sections 3.1 and 3.2 for identification of soil constraints and Section 4 for management options. Key soil properties for assessing constraints indicated in Table 20.
- Productive and resilient rural sector	Methodology and interpretive guidelines for identifying and managing soil constraints.	Sections 3.1 and 3.2 for identification of soil constraints and Section 4 for management options. Key soil properties for assessing constraints indicated in Table 20.
	Soil and nutrient management 'packages' for delivery to farmers based on the principles of soil/site specific management	Sections 5.1 and 5.2.

9. RECOMMENDATIONS FOR FUTURE IMPLEMENTATION AND ENHANCEMENTS OF THE GUIDELINES ACROSS THE ASEAN REGION

9.1 Spatial characterisation of soil resources and constraints

The Fertility Capability Classification (FCC) system which utilises available soil survey data has been shown to be extremely useful for assessing the capability and constraints of upland and lowland soils in various parts of Brunei Darussalam, Cambodia, Philippines, Thailand and Vietnam (Section 2.2). The standardised methodology and constraints criteria could be applied to soil survey datasets across the entire ASEAN region, allowing a harmonised regional assessment of soil resources. This assessment could be used for such diverse purposes as identifying good quality agricultural land for land planning purposes and prioritising investment for soil amelioration and remediation.

- It is recommended that available soil survey information is collated to produce a regional series of spatial soil capability and soil constraint products. These products could be used to inform policy initiatives and extension activities focussed on food security, identify appropriate climate-smart agricultural systems, and prioritise the protection of the ecosystem services provided by the soil resource from land degradation.

9.2 Harmonised approach to site specific nutrient management

The site/soil specific nutrient management methodology (SSNM) has been utilised in several ASEAN Member States to customise nutrient inputs into rice and maize cropping systems (Section 5.2). This methodology is scientifically robust and offers a precise approach for determining nutrient inputs that maximise crop nutrient uptake efficiency. This approach has been shown to maximise farmer profitability while minimising off-site nutrient movement. The methodology is crop-specific and can be extrapolated across regions and soil types. The nutrient budgeting approach to SSNM (Fig. 3) could be easily harmonised across the ASEAN region by standardising the nutrient requirements of focus crops. Regional adoption of the soil/plant test approach to SSNM (Fig. 4) would be more challenging because assessing the indigenous soil nutrient supply requires calibrated soil tests or plant indices (e.g., LCC). However, this approach is more practical because it does not require on-farm plots to measure crop uptake from indigenous nutrient sources.

- It is recommended that: (a) standardised crop nutrient requirement charts (kg nutrient in crop biomass/unit crop yield) are developed for focus crops in the region; and (b) regional calibrations are developed for specified soil tests (e.g., Olsen-P, exchangeable K) and plant indices (e.g., LCC for N)

9.3 Standardisation of soil test kit methodology and interpretation

Soil test kits are used in several ASEAN Member States to qualitatively assess soil nutrient status as low-medium-high, or to quantitatively measure soil nutrient status for determining indigenous soil nutrient supply. While it is recognised that these soil test kits are generally supplied under proprietary licencing arrangements, there is a great opportunity to compare the methodologies and outputs of the various soil test kits and develop a standard set of protocols for determining and interpreting soil nutrient status.

Soil test kit methodology could be integrated into a mobile technical information-extension delivery platform based on the highly successful Soils Doctor program used in Thailand.

- It is recommended that methodologies and outputs of the various soil test kits are reviewed and compared to develop standardised protocols for interpreting outputs in terms of nutrient requirements. Increased adoption of this harmonised methodology across the ASEAN region might be facilitated by the initiation of public private partnerships to expand market access.
- It is recommended that integration of the soil test kit methodology into a mobile technical information-extension delivery platform be investigated, again with public private partnership arrangements being considered.

9.4 Harmonising standards and labelling requirements for fertilizers and supplements

There are already some commonalities in the standards and labelling requirements for fertilizers and supplements (such as composts) in the ASEAN region (Section 6). However, it would greatly benefit and inform farmers and other users of these products if there was a uniform fertilizer/supplement code for constituents and labelling across the ASEAN region.

- It is recommended that a review be undertaken of the standards and labelling regulations of the ASEAN Mmember States with a view to developing standardised fertilizer and supplement codes across the region.

9.5 Formalising quality assurance/quality control in soil and plant testing laboratories

Accreditation/certification schemes (e.g., ISO Standards) already exist for quality assurance/quality control in analytical laboratories and are held by some AMS laboratories (viz. Bureau of Soil and Water Management, Philippines; Plant Health Laboratory Department, AVA, Singapore; Soils and Fertilizers Research Institute, Vietnam). The ISO certification system verifies that the laboratory has Quality Assurance/Quality Control procedures and processes in place. However this certification system does not assess the ability of a laboratory to follow the standard operating procedure of a specified analytical method (for example the Bray II soil test) and produce comparable results to other labs undertaking the same test. Because soil (and to a lesser extent, plant) tests are often empirical, strict adherence to methodology is required (Section 6), and it is a challenge to ensure all laboratories obtain repeatable results for a sample. This is best achieved through a certification scheme based on a formal Inter Laboratory Proficiency Testing (ILPT) Program such as the WEPAL, Netherlands, ILPT programme in which the Plant Health Laboratory Department, AVA, Singapore participates. A similar ILPT program is run by the Australasian Soil and Plant Analysis Council (ASPAC) and several laboratories of the informal network of soil testing laboratories already existing in the ASEAN region- the South East Asian Laboratory Network (SEALNet)- are sponsored participants in the ASPAC ILPT. SEALNet could initiate such a program itself for ASEAN soil and plant testing laboratories, thereby ensuring quality assurance/quality control practices and processes are undertaken by laboratories providing soil and plant analyses to the agricultural sector.

- It is recommended that SEALNet be formally recognised and supported as the peak regional organisation responsible for ensuring quality assurance/quality control in laboratories providing soil and plant analyses to the agricultural sector in the ASEAN region.

9.6 Development of a regional ICT strategy to support policy, planning and support services for soil and nutrient management

Because of limited resources and the scarcity of trained technical, scientific and extension personnel, there is currently an inability in most ASEAN Member States to provide farmers with timely up-to-date advice. The same comment applies to the availability of relevant timely advice to policy-makers on soil and land management issues because there is often an information and communication disconnect between agencies. A regional ICT program supporting e-Agriculture, with a soil and nutrient management component, would greatly facilitate the rapid exchange of information and provide a platform for communication and capacity-building.

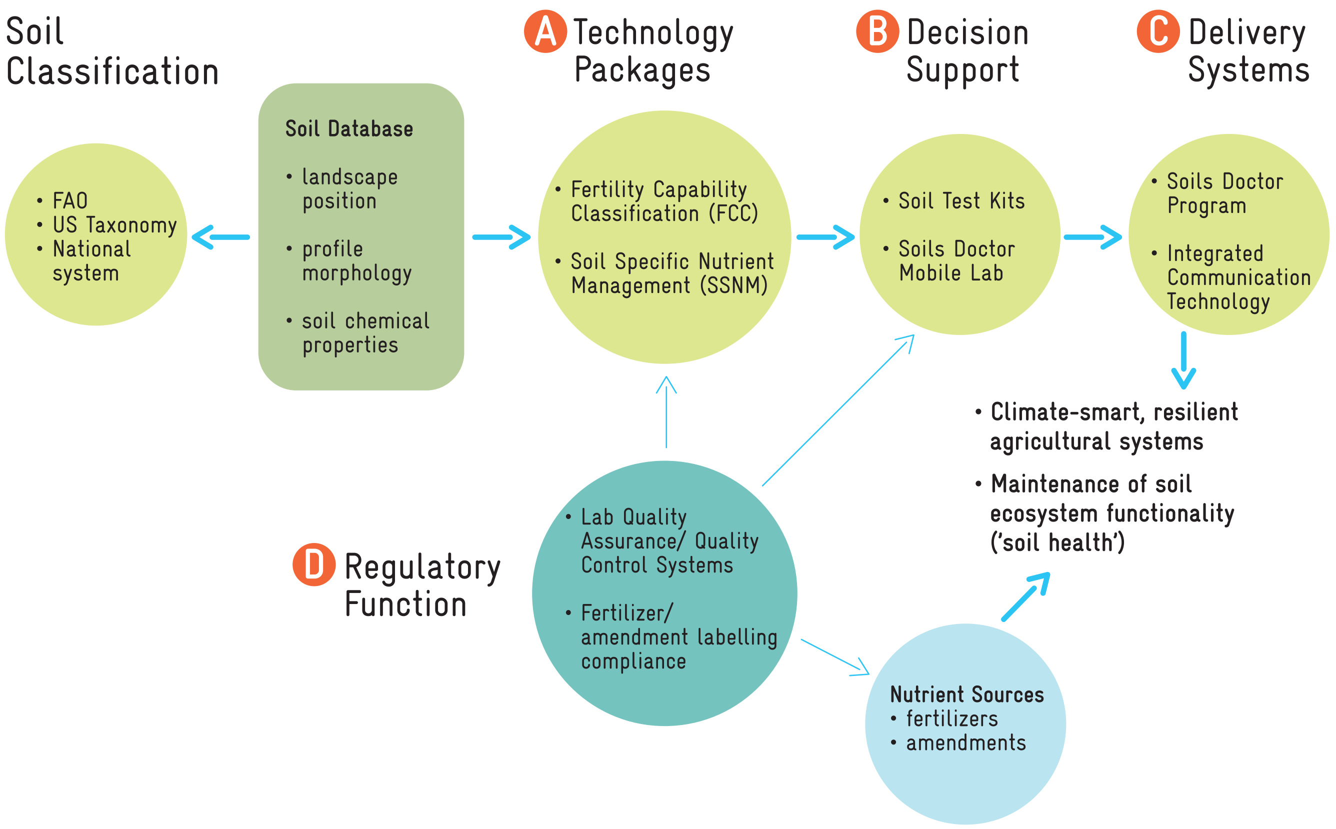
- It is recommended that the need for a regional e-Soil and Nutrient program be formally recognised and supported, with resource hubs taking e-input from end-users and providing advice, information and training back to the end-user. Setting up and implementing such a program could be informed by the FAO-ITU (2016) strategy.

- As an initial step in the application of ICT to soil and nutrient management, a dedicated Soil and Nutrient Management page could be implemented in the ASEAN Cooperation on Crops website as the first regional communication platform to support policy, planning and support services for soil and nutrient management.

9.7 Implementation framework and schedule

The above *Guidelines on Soil and Nutrient Management* are the technical base of a proposed *Implementation Framework for Soil and Nutrient Management* in the ASEAN region (Fig. 6).

Figure 6 **Implementation Framework for Soil and Nutrient Management in the ASEAN region**



This *Implementation Framework for Soil and Nutrient Management* addresses the following goals in the Vision and Strategic Plan for ASEAN Cooperation in Food, Agriculture and Forestry (2016-2025): 'Ensuring food security, food safety and better nutrition', and 'Increasing resilience to, and contributing to, mitigation and adaptation of climate change, natural disasters and other shocks'.

Specifically the *Implementation Framework* addresses Strategic Thrust 3/Action Program 3.1 of this document, namely: 'Effectively implement the ASEAN Integrated Food Security (AIFS) Framework and Strategic Plan of Action on Food Security in ASEAN Region (SPA-FS, 2015-2020)'.

Other Strategic Thrusts/Action Programmes in the ASEAN Vision and Strategic Plan that are also addressed by the *Implementation Framework* include:

- Strategic Thrust 1 (Sustainable 'green' technologies, resource management systems) 1.2, 1.3, 1.4, 1.5, 1.9, 1.12 and 1.13;
- Strategic Thrust 2 (Trade and economic integration) 2.2;
- Strategic Thrust 4 (Resilience to climate change) 4.1, 4.2, 4.3, 4.6, and 4.7.

Implementation of regional soil and nutrient management is necessarily underpinned by: (A) Technology Packages, (B) Decision Support Systems, (C) Delivery Systems and (D) Regulatory Functions (Fig. A). During the development of the Guidelines, the following exemplar packages and systems were identified that could be integrated regionally to achieve the implementation of climate-smart and resilient agricultural systems and maintain/improve soil health:

(A) The **Fertility Capability Classification (FCC)** methodology can be applied to regional soil databases to identify, and provide an inventory of, soil constraints to productive agricultural systems and risk of land degradation. The FCC methodology also identifies management options for amelioration/mitigation.
Soil Specific Nutrient Management (SSNM) methodology can be used to implement integrated nutrient inputs and practices so that nutrient use efficiency (i.e., nutrient taken up by the crop/unit of nutrient applied) is optimised for farmer profitability and environmental benefit.

(B) Input information and decision support for SSNM can be provided by **Soil Test Kits** and **Mobile Labs** that provide on-the-spot soil fertility assessment. Ideally, this assessment should be calibrated against crop yield response to provide nutrient recommendations.

(C) Technical advice, training and capacity-building can be delivered regionally by **Integrated Communication Technology (ICT)** and, on-the-ground, by programs such as the **Soils Doctor Program** in Thailand. With further development, ICT could be the primary delivery platform for directly connecting regionally-based technical and extension advice 'hubs' to individual farmers.

(D) Reliable and reproducible analytical data, such as the chemical composition of fertilizer and amendments to meet regulated labelling requirements, and soil and plant analytical input into the FCC and SSNM decision support systems, must be underpinned by certified laboratory **Quality Assurance systems.** Certification for an analysis is evidence that the lab is able to provide reproducible and reliable results in agreement with results from other regional labs. This certification is essential for consistency in regional programs.

Process, outputs, outcomes and timeframes for the implementation of soil and nutrient management in the ASEAN region are documented in Table 22.

Because of the technical nature of the outputs and expected outcomes, the implementation process will need to be driven by two formalised expert teams comprising nominated scientists/extensionists from ASEAN Member States. The Technical Expert Implementation Group will require knowledgeable and experienced soil scientists with a detailed understanding of agricultural production systems. The Extension Expert Implementation Group will require knowledgeable and experienced agricultural extensionists with a detailed understanding of the socio-economics of rural communities and linkages with agri-business. These two Expert Groups will need to work in close collaboration to review existing information and to facilitate/champion/initiate new activities to achieve the outputs. A process to allow ASEAN policy and planning input into the new activities and outputs will be required to maximise the impact of the outcomes.

Table 22 **Implementation schedule for soil and nutrient management in the ASEAN region**

Component	Implementation process	Output	Outcome	Timeframe/ priority
A Technology packages				
Fertility Capability Classification (FCC) *(SNM Guidelines Section 2.2)*	ASEAN Technical Expert Implementation Group	Harmonised set of soil FCC modifiers and constraints for ASEAN region	Regional inventory/maps of - good quality agricultural land; - soils at risk of degradation; - 'problem soils' *(SNM Guidelines Section 3.1)*; - individual soil constraints *(SNM Guidelines Section 3.2)* with associated GSMP *(SNM Guidelines Sections 4.1-4.4)*	Short term High priority
Soil Specific Nutrient Management (SSNM) *(SNM Guidelines Section 5.2)*	ASEAN Technical Expert Implementation Group ASEAN Extension Expert Implementation Group	SSNM protocols and nutrient recommendations for rice and maize across the ASEAN region	SSNM protocols and procedures that can be applied to other focus crops across the ASEAN region	Medium term High priority

Component	Implementation process	Output	Outcome	Timeframe/ priority
B Decision support Soil Test Kits *(SNM Guidelines Section 5.2)*	ASEAN Technical Expert Implementation Group	Review of soil fertility categories and interpretation guidelines for soil test kits used in the ASEAN region *(SNM Guidelines Section 5.2.1)*	Harmonised soil fertility categories and interpretation guidelines for soil test kits used in the ASEAN region	Medium term Medium priority **Opportunity for public-private partnerships**
Soils Doctor Mobile Lab *(SNM Guidelines Section 5.2)*	ASEAN Technical Expert Implementation Group ASEAN Extension Expert Implementation Group	Mobile soils lab protocols and nutrient recommendations standardised and harmonised with outputs from soil test kits across the ASEAN region	Soil test protocols and procedures that can be applied for soil fertility assessment across the ASEAN region	Medium term Medium priority **Opportunity for public-private partnerships**
C Delivery systems Soils Doctor program	ASEAN Technical Expert Implementation Group ASEAN Extension Expert Implementation Group	Review principles used in the Soils Doctor program for extending technical information on soil and nutrient management to farmers	Principles and guidelines that can be applied for extending technical information on soil and nutrient management to ASEAN farmers *(aligning with the advice on soil and nutrient management practices provided in Sections 4 & 5)*	Short term High priority
Integrated Communication Technology *(SNM Guidelines Section 7.3)*	ASEAN Technical Expert Implementation Group ASEAN Extension Expert Implementation Group	- Implement a dedicated Soil and Nutrient Management page in the 'ASEAN Cooperation on Crops' website. - Develop Soil and Nutrient Management ICT plan for submission to AMAF for support	Interactive information dialogue between farmer and technical/extension experts to provide decision support via Smartphone technology	Long term Medium priority

Component	Implementation process	Output	Outcome	Timeframe/ priority
D Regulatory Functions Lab QA/QC *(SNM Guidelines Section 7.1)*	South East Asian Laboratory Network (SEALNet)	- Uniform Standard Operating Procedures for ASEAN soil testing labs - QA/QC certification program for ASEAN labs	Certification for an analysis is evidence that the lab is able to provide reproducible and reliable results in agreement with results from other regional labs	Medium term High priority
Compliance labelling *(SNM Guidelines Section 6)*	ASEAN Technical Expert Implementation Group	Agreed minimum standards for labelling fertilizers and supplements in the ASEAN region	Harmonised fertilizer and supplement labelling regulations in the ASEAN region	Short term Medium priority

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11. ATTACHMENT 1: METADATA FOR NATIONAL SOIL MAPS

11.1 Brunei Darussalam

Information	Data description
Project name	(Hunting Soil Map)Land Capability Study for Brunei Darussalam , Hunting Technical Service LTD
Custodian	Department of Agriculture and Agrifood Brunei Darussalam
Format	Raster File (ecw, ers)
Scale	1:100,000
Content	- Soil Characteristics , Land Form, Forest Type, Land Slope and Land Use
Project reference documents	- Hunting Technical Services LTD - Land Capability Study Volume II Physical Resources and development Priorities, February 1969

Information	Data description
Project name	Soil Fertility Evaluation/Advisory Service In Brunei Darussalam 2007
Custodian	Department of Agriculture and Agrifood, Brunei Darussalam
Format	Raster File (ecw, ers), Shapefile, points, Line, satellite imagery
Scale	-
Content	- Soil Classification, Sampling Locations, Field and Laboratory data, Land suitability , Soil and Acid Sulphate Soil Hazard Maps
Project reference documents	- Report P1 - 1.1 - Laboratory Analysis of Soil Chemical and Physical Properties. - Report P2 - 3 - Acid Sulfate Soils. - FAO (1976) 'A Framework for Land Evaluation.' Soils Bulletin 32,FAO, Rome. - Report P1 - 2 - Soil Properties and Soil Identification Key for Major Soil Types. - Hunting Technical Services (1969) 'Land Capability Study'. Hunting Technical Services Ltd., Herts, UK. - Report P2 - 1 - Suitability of Major Soil Types for Cropping. - Soil Survey Staff (2003) 'Keys to Soil Taxonomy'. 9th Edition. - United States Department of Agriculture - Natural Resources Conservation Service - ULG Consultants (1982) 'Brunei Agricultural and Forestry Development Study'. ULG Consultants Ltd through Brunei Shell Petroleum Co. Ltd, Bandar Seri Begawan, Brunei Darussalam. - ULG Consultants (1983) 'The Temburong Renewable Resources Study'. ULG Consultants Ltd through Brunei Shell Petroleum Co. Ltd, Bandar Seri Begawan, Brunei Darussalam. - Darussalam Report P1 - 3/4 - Fertility and Limitations to Cultivation of Major Soil Types.

Information	Data description
Project name	- Brunei Agriculture And Forestry Development Study, **Inter-Riverine Zone** Map (10A, 10B, 14A, 14B, 20A, 20B, 20C, 20D, 21A, 21B, 21C, 21D) Soils. - Brunei Agriculture And Forestry Development Study, **Inter-Riverine Zone** Map 11A & 11B **Soil observation network.** - Brunei Agriculture And Forestry Development Study, **Inter-Riverine Zone** Map 12A & 12B **Land use.** - Brunei Agriculture And Forestry Development Study, **Inter-Riverine Zone** Map 13A & 13B **Land-Forms.** - Brunei Agriculture And Forestry Development Study, **Inter-Riverine Zone** Map 14A, 14B, 21a, 21b, 21c, 21d **Land Units.** - Brunei Agriculture And Forestry Development Study, **Inter-Riverine Zone** Map 20a, 20b, 20c, 20d **Soils & Land-Forms.** - Brunei Agriculture And Forestry Development Study, **Labi Study Area Map** 1(North) & 2(south) **Soils** - Brunei Agriculture And Forestry Development Study, **Labi Study Area Map** 3(North) & 4(south) **Land Use.** - Brunei Agriculture And Forestry Development Study, **Labi Study Area Map** 5(North) & 6(south) **Land-Forms.** - Brunei Agriculture And Forestry Development Study, **Labi Study Area Map** 7(North) & 8(south) **Land Units.** - Brunei Agriculture And Forestry Development Study, Labi Hills & Ladan Hills Forest Reserves And Inter-Riverine Zone **Forest Type Map Sheet F4,F5,F6 & F7.** - Temburong Renewable Resources Study, **Labu Study Area Map** 1E & 1W and **soil observation.** - Temburong Renewable Resources Study, **Labu Study Area Map** 2E & 2W **Land-Forms.** - Temburong Renewable Resources Study, **Labu Study Area Map** 3E & 3W **Land Use.** - Temburong Renewable Resources Study, **Labu Study Area Map** 4E & 4W **Land Units.** - Temburong Renewable Resources Study, **Labu Study Area Map** 5W **Land Use Plan.** - Temburong Renewable Resources Study, **Labu Study Area Map** 6N & 6S **Soils & Slopes.** - Temburong Renewable Resources Study, **Labu Study Area Map** 7N & 7S **Land Use.** - Temburong Renewable Resources Study, **Labu Study Area Map** 8N & 8S **Land Units.** - Temburong Renewable Resources Study, **Labu Study Area Map** F2, F8 & F9 **Forest Type.** - Temburong Renewable Resources Study, **Labu Study Area Map** 9 **Soils Observations Network.**
Custodian	Department of Agriculture and Agrifood Brunei Darussalam
Format	Raster File (ecw, ers)
Scale	1:50,000 , 1:25,000 , 1:12,500 , 1:10,000
Content	- Soil Profiles, soil classification, soil type, Land use, forest type, Land units, land forms, contour, land slopes
Project reference documents	- ULG Consultants (1982) 'Brunei Agricultural and Forestry Development Study'. ULG Consultants Ltd through Brunei Shell Petroleum Co. Ltd, Bandar Seri Begawan, Brunei Darussalam. - ULG Consultants (1983) 'The Temburong Renewable Resources Study'. ULG Consultants Ltd through Brunei Shell Petroleum Co.Ltd, Bandar Seri Begawan, Brunei Darussalam.

11.2 Cambodia

Information	Data Description
Project name	General Soil Map of Cambodia 1963
Custodian	Surveyed and drafted by Mr. Charles D. Crocker, U.S.A.I.D with collaboration of the National Commission of Land Use. Drawn and printed by the SERVICE GEOGRAPHIQUE DES F.A.R.K., PHNOM PENH, 1963. Edited by MINISTRY OF AGRICULTURE
Format	Arcinfo
Scale	1:1,000,000
Content	USDA classification System
REF	U.S.A.M.S. NC 48 - ND 48

Information	Data Description
Project name	Soil Map of Cambodia, LMB - 1998 - 2001
Custodian	Agricultural Soil Unit, Department of Planning, Statistic and International Cooperation (MAFF)
Format	Arcinfo
Scale	1:500,000
Content	FAO/UNESCO 1989

11.3 Indonesia

Information	Data Description
Project name	Land Resources Evaluation and Planning Project (LREPP) 1988
Custodian	Surveyed and drafted by Agus B. Siswanto, Yayat A. Hidayat, Arief Syarifuddin, Bambang Kaslan, Yayat H. Sopandi, Sunaryo, Sambas, Wawan G., Sucianto T., and Mujiono. Edited by Nata Suharta, M. Soekardi, and H. Suhardjo (Java Island); H. Suhardjo and Subagyo H. (Sumatra Island); Agus B. Siswanto and Nata Suharta (Kalimantan Island); Marsoedi Ds, Sawiyo, and Sofyan Ritung (Sulawesi and Moluccas Islands); D. Djaenudin and M. Soekardi (Bali, Nusatenggara, and Papua Islands). Steering Committee: Dr. Joko Budianto, Dr. Abdurachman Adimiharja, and Dr. A. Hidayat. DEPARTMENT OF AGRICULTURE
Format	Shapefile
Scale	1:1,000,000
Content	USDA classification System

11.4 Lao PDR

Information	Data description
Project name	Soil survey of Laos: 1990-1995
Custodian	Soil Survey and Land Classification Center/Department of Agriculture/ Director: Dr Ty Phommasak Nongviengkham village, Xaythany district, Vientiane, Lao PDR
Format	ESRI (ARVIEW 3.2; ARGIS 10X.)
Scale	Country scale: 1:1,000,000
content	- FAO system (UNESCO 1989) - Paper map published in 2000 - 2405 Soil profiles with detail description and properties
Project reference document	The basic information of main soil units of Laos (Agriculture Land Use Planning Center)

11.5 Malaysia

Information	Data Description
Project Name	Soil Map of Peninsular Malaysia
Custodian	Soil Survey Section, Soil Resource Management & Conservation Division, Department of Agriculture, Malaysia
Format	ArcGIS ArcView 10.3.1
Scale	1:3,000,000
Content	- Peninsular Malaysia Classification System - FAO Classification System
Project Reference Documents	FAO-UNESCO, 2001

11.6 Myanmar

Information	Data description
Project name	Soil map of Myanmar - 1955 - 57
Custodian	Land Use Bureau Russian Expert: Dr. B.G Rosanov
Format	Mapinfo ver. 11.5
Scale	1:253,000
Content	- Russian Method - Paper map published in 1976 - Digitized in 1999 - 63 Aerial Photo interpretation and Photo mosaics
Project reference documents	N/A

Information	Data description
Project name	Soil Map of Myanmar - 1970
Custodian	Land Use Division (MAS) Director: U Ba Than
Format	Mapinfo. 11.5
Scale	1:253,000
Content	- Russian classification system - Paper map published in 1970 - Base on the Taxonomy, Nomenclature
Project reference documents	Report of soil map of Myanmar - 1981

Information	Data description
Project name	Soil Map of Myanmar - 1980
Custodian	Land Use Division Director: Dr. NyanHtun
Format	Mapinfo. 7.5
Scale	1:253,000
Content	- FAO/UNESCO classification - Paper map published in 1969 - Reedited and Digitized in 1998
Project reference documents	NA

Information	Data description
Project name	Soil map 2004 - States Divisions of Myanmar
Custodian	Land Use Division Department of Agriculture Director: Dr. Nyi Nyi
Format	Mapinfo. 11.5 Digitized
Scale	1:63360
Content	- 500 main soil profiles with analyzed samples, soil depth 0 - 50 cm. - 150 main soil profiles without analyzed samples, soil depth 0 - 90 cm. - Soil classified by FAO Classification system - Analyzed soil properties: Physical: Soil texture Chemical: pH:H_2O and EC; exchangeable acidity; Total OC; Total N, P_2O5, K_2O, available; H^+, Fe^{3+}, Al^{3+}; Ca^{2+}, Mg^{2+}, K^+, Na^+ exchangeable; CEC in soil and clay Additional properties: 5/Soil chemical and physical analyses according to Analysis Standards of FAO.
Project reference documents	Soil Types & Characteristics of Myanmar, 2004. LUD, MOAI

Information	Data description
Project name	2014 - 15 Districts & Townships of Myanmar
Custodian	Land Use Division, DOA Director: Soe Win, LUD, DOA, Nay Pyi TAW
Format	Arc GIS
Scale	Regional: 1:1,500,000; District: 1:750,000; Township: 1:500,000
Information	Data description
Content	- 100 main soil profiles with analyzed samples, soil depth 0 - 120 cm. - 500 main soil profiles without analyzed samples, soil depth 0 - 120 cm. - Soil classified to FAO soil Unit (FAO-UNESCO,2006) - Soil chemical and physical analyses according to Analyses Standards of FAO
Project reference documents	Final report of soil map of Myanmar

Note: Not published yet

11.7 Philippines

Information	Data Description
Project Name	Classification and Mapping of Philippine Soils
Custodian	Bureau of Soils and Water Management (BSWM)
Format	Book Type
Scale	1:1,600,000
Content	Soil Mapping at Higher Levels of Soil Classification
Project reference documents	Carating, R.B., R.G. Galanta and C.D. Bacatio. 2014. The Soils of the Philippines. Bureau of Soils and Water Management, Diliman, Quezon City, Philippines

11.8 Thailand

Information	Data Description
Project Name	Soil Survey in Provincial Level Project (1967 - 1984)
Custodian	Soil Survey Division, Land Development Department, Ministry of Agriculture and Cooperatives
Format	Shapefiles (.shp)
Scale	1:100,000
Content	- Data: Soil Series Map (Soil Taxonomy, USDA) and soil properties data - Coordinate System: UTM Indian 1975 Zone 47N and 48N
Project reference documents	- Soil Survey Reports (by province) - Detailed Reconnaissance Soil Maps (by province)

Information	Data Description
Project Name	Land Utilization for Cash Cropping Project (1987 - 1991)
Custodian	Soil Survey and Classification Division, Land Development Department, Ministry of Agriculture and Cooperatives
Format	Shapefiles (.shp)
Scale	1:50,000
Content	- Data: Soil Series Groupings Maps, Soil Properties and Management - Coordinate system: UTM Indian 1975 Zone 47N and 48N
Project reference documents	- Land Utilization for Cash Crops Reports (by province) - Groups of Soil Series for Cash Cropping Manual

Information	Data Description
Project Name	The Soil Resources of Thailand
Custodian	Soil Survey and classification Division, Department of Land Development, Ministry of Agriculture and Cooperatives
Format	Shapefiles (.shp) created a digital soil map from a printed version
Scale	1:1,2000,000
Content	- Data: Great group of Soil Taxonomy, using particle size classes as modifiers - Coordinate system: UTM WGS 1984 Zone 47N
Project reference documents	Pisoot Vijarnsorn and Hari Eswaran. 2002. The Soil Resources of Thailand. 17th WCSS in Bangkok, Thailand

Information	Data Description
Project Name	Soil Mapping and Soil Survey Report for Agriculture in Provincial Level at Scale 1:25,000 Project (2005-2010)
Custodian	Office of Soil Survey and Land use planning, Land Development Department, Ministry of Agriculture and Cooperatives
Format	Shapefile (.shp)
Scale	1:25,000
Content	- Data: Soil Groups Maps and Soil Properties - Coordinate system: UTM WGS 1984 Zone 47N and 48N
Project reference documents	- Soil Survey of Agriculture Reports (by province)

Information	Data Description
Project Name	The revision of national WRB soil map of Thailand
Custodian	Soil Resources Survey and Research Division, Land Development Department, Thailand
Format	Shapefiles (.shp)
Scale	1:1,0000,000
Content	- Data: Reference Soil Groups combined with principal qualifiers (WRB, 2014) with particle size classes as modifiers or phase - Coordinate system: UTM WGS 1984 Zone 47N
Project reference documents	The World Reference Base for Soil Resources Map of Thailand Report

11.9 Vietnam

Information	Data description
Project name	Soil map of Vietnam - 1976
Custodian	Soil genesis and classification Division/Soils and Fertilizers Research Institute/Director: Nguyen Xuan Lai Le Van Hien street - Duc Thang ward - Bac Tu Liem dist. - Ha Noi, Vietnam
Format	Mapinfo ver. 11.5
Scale	1:1,000,000
Content	- Vietnamese classification system - Paper map published in 1976 - Digitized in 1999 - 63 soil profiles with detail description and properties
Project reference documents	The basic information of main soil units of Vietnam" (Soils and Fertilizers Research Institute, 2002).

Information	Data description
Project name	Soil map of the North of Vietnam - 1979
Custodian	Soil genesis and classification Division/Soils and Fertilizers Research Institute/Director: Nguyen Xuan Lai Le Van Hien street - Duc Thang ward - Bac Tu Liem dist. - Ha Noi, Vietnam
Format	Mapinfo 11.5
Scale	1:500,000
Content	- Vietnamese classification system - Paper map published in 1979 - Digitized in 2005
Project reference documents	Report of soil map of the North of Vietnam - 1981

Information	Data description
Project name	Soil map of the Red River Delta
Custodian	Soil genesis and classification Division/Soils and Fertilizers Research Institute/Director: Nguyen Xuan Lai Le Van Hien street - Duc Thang ward – Bac Tu Liem dist. – Ha Noi, Vietnam
Format	Mapinfo 7.5
Scale	1:250,000
Content	- Vietnamese classification system - Paper map published in 1969 - Reedited and Digitized in 1998
Project reference documents	NA

Information	Data description
Project name	Researching on the changes of saline and acid sulphate soils in Red River Delta (RRD) and Mekong River Delta (MRD) after 30 years of use (1975 - 2005)
Custodian	Soil genesis and classification Division/Soils and Fertilizers Research Institute/ Director: Nguyen Xuan Lai Le Van Hien street - Duc Thang ward - Bac Tu Liem dist. - Ha Noi, Vietnam
Format	Mapinfo 11.5
Scale	Map of Red River Delta 1:100,000 ; Mekong River Delta 1:250,000
Content	1/RRD: - 100 main soil profiles with analyzed samples, soil depth 0 - 120 cm. - 940 main soil profiles without analyzed samples, soil depth 0 - 120 cm 2/MRD: - 397 main soil profiles with analyzed samples, soil depth 0 - 120 cm. - 4.540 main soil profiles without analyzed samples, soil depth 0 - 120 cm 3/Soil classified by Vietnamese Classification system 4/Analyzed soil properties: - Physical: Soil texture, bulk density, particle density, porosity, moisture - Chemical: pHH2O and pHKCl; EC; exchangeable acidity & Potential acidity; Total OC; Total N, P_2O_5, K_2O; P_2O_5, K_2O available; H^+, Fe^{3+}, Al^{3+}; Ca^{2+}, Mg^{2+}, K^+, Na^+ exchangeable; CEC in soil and clay; BS. - Additional properties: + Acid sulphate soil: SO_3^{2-} total, SO_4^{2-} mobile, Fe total, Fe^{3+} soluble. + Saline soil: EC, Cl - and total soluble salts. 5/Soil chemical and physical analyses according to Analysis Standards of Vietnam and Analysis Manual of Soils & Fertilizers Research Institute, 1998
Project reference documents	Final Report: Researching on the changes of saline and acid sulphate soils in Red River Delta (RRD) and Mekong River Delta (MRD) after 30 years of use (1975 - 2005)

Information	Data description
Project name	Studying on improvement the effectiveness of agricultural land resources in the Northwest of Vietnam, 2014
Custodian	Soil genesis and classification Division/Soils and Fertilizers Research Institute/ Director: Nguyen Xuan Lai Le Van Hien street - Duc Thang ward - Bac Tu Liem dist. - Ha Noi, Vietnam
Format	Mapinfo 11.5
Scale	Provincial level 1:100,000 ; regional level 1:250,000
Content	- 350 main soil profiles with analyzed samples, soil depth 0 - 120 cm - 3.150 main soil profiles without analyzed samples, soil depth 0 - 120 cm. - 3.000 top soil samples, 0 - 20 cm. - Soil classified to FAO soil Unit (FAO - UNESCO - WRB, 2006) - Soil chemical and physical analyses according to Analysis Standards of Vietnam and Analysis Manual of Soils & Fertilizers Research Institute, 1998
Project reference documents	Final report: Studying on improvement the effectiveness of agricultural land resources in the Northwest of Vietnam, 2014

Information	Data description
Project name	Evaluation of agricultural soil resource for sustainable land use planning of Bac Ninh province
Custodian	Soil genesis and classification Division/Soils and Fertilizers Research Institute/ Director: Nguyen Xuan Lai Le Van Hien street - Duc Thang ward - Bac Tu Liem dist. - Ha Noi, Vietnam
Format	Mapinfo 11.5
Scale	Provincial level 1:25,000 ; district level 1:10,000
Content	- 239 main soil profiles with analyzed samples, soil depth 0 - 120 cm. - 2.151 main soil profiles without analyzed samples, 0 - 120 cm. - 717 top soil samples, 0 - 20 cm. - Soil classified to FAO soil sub-Unit (FAO - UNESCO - WRB, 1998 & 2001) - Soil chemical and physical analyses according to Analysis Standards of Vietnam and Analysis Manual of Soils & Fertilizers Research Institute, 1998
Project reference documents	Final report for districts and province, 2008

Information	Data description
Project name	Soil surveying and land evaluation for agricultural land resource of Hung Yen district (2012-2014)
Custodian	Soil genesis and classification Division/Soils and Fertilizers Research Institute/ Director: Nguyen Xuan Lai Le Van Hien street - Duc Thang ward - Bac Tu Liem dist. - Ha Noi, Vietnam
Format	Mapinfo 11.5
Scale	Provincial level 1:50,000 ; district level 1:25,000
Content	- 82 main soil profiles with analyzed samples, soil depth 0 - 120 cm. - 580 main soil profiles without analyzed samples, soil depth 0 - 120 cm. - 340 top soil samples, 0 - 20 cm - Soil classified to FAO soil sub-Unit (FAO - UNESCO - WRB, 2006) - Soil chemical and physical analyses according to Analysis Standards of Vietnam and Analysis Manual of Soils & Fertilizers Research Institute, 1998
Project reference documents	Final report for districts and province, 2014

Information	Data description
Project name	Assessing the agricultural land resource of Thai Binh province, (2011 - 2013)
Custodian	Soil genesis and classification Division/Soils and Fertilizers Research Institute/ Director: Nguyen Xuan Lai Le Van Hien street - Duc Thang ward - Bac Tu Liem dist. - Ha Noi, Vietnam
Format	Mapinfo 11.5
Scale	Provincial level 1:50,000 ; district level 1:25,000
Content	- 80 main soil profiles with analyzed samples, soil depth 0 - 120 cm - 670 main soil profiles without analyzed samples, soil depth 0 - 120 cm - 750 top soil samples, 0 - 20 cm. - Soil classified to FAO soil sub-Unit (FAO - UNESCO - WRB, 2006) - Soil chemical and physical analyses according to Analysis Standards of Vietnam and Analysis Manual of Soils & Fertilizers Research Institute, 1998
Project reference documents	Final report for districts and province, 2013

Information	Data description
Project name	Assessing the agricultural land resource of Nam Dinh province, (2015 - 2016)
Custodian	Soil genesis and classification Division/Soils and Fertilizers Research Institute/ Director: Nguyen Xuan Lai Le Van Hien street - Duc Thang ward - Bac Tu Liem dist. - Ha Noi, Vietnam
Format	Mapinfo 11.5
Scale	Provincial level 1:50,000
Content	- 55 main soil profiles with analyzed samples, soil depth 0 - 120 cm - 450 main soil profiles without analyzed samples, soil depth 0 - 120 cm - Soil classified to FAO soil sub - Unit (FAO - UNESCO - WRB, 2006) - Soil chemical and physical analyses according to Analysis Standards of Vietnam and Analysis Manual of Soils & Fertilizers Research Institute, 1998
Project reference documents	Final report for Nam Dinh province, 2016

Information	Data description
Project name	Studying on the soil fertility constraints for rice - based areas of RRD & MRD (2011 - 2014)
Custodian	Soil genesis and classification Division/Soils and Fertilizers Research Institute/ Director: Nguyen Xuan Lai Le Van Hien street - Duc Thang ward - Bac Tu Liem dist. - Ha Noi, Vietnam
Format	Word 2010
Scale	No
Content	- 720 top soil samples, 0 - 20 cm. - Soil chemical and physical analyses according to Analysis Standards of Vietnam and Analysis Manual of Soils & Fertilizers Research Institute, 1998 - Soil classified: NA
Project reference documents	Studying on the soil fertility constraints for rice - based areas of RRD & MRD (2011 - 2014)

Information	Data description
Project name	Studying and identifying the quality and quantity of grey degraded soils in the North Vietnam
Custodian	Soil genesis and classification Division/Soils and Fertilizers Research Institute/ Director: Nguyen Xuan Lai Le Van Hien street - Duc Thang ward - Bac Tu Liem dist. - Ha Noi, Vietnam
Format	Mapinfo 11.5
Scale	- 1:50,000 for area grey degraded soils of 13 provinces (Thua Thien Hue, Quang Binh, Ha Tinh, Nghe An, Thanh Hoa, Hai Duong, Ha Noi, Bac Ninh, Quang Ninh, Bac Giang, Thai Nguyen, Vinh phuc, Phu Tho) - 1:250.000 for area grey degraded soils in the North of Vietnam
Content	- 120 soil profiles described to 120 cm, - 500 top soils samples (0 - 20 cm) - Soil chemical and physical analyses according to Analysis Standards of Vietnam - Soils classified according Vietnam classification system
Project reference documents	Soil survey 2010 - 2013 - Database of grey degraded soils in northern of Vietnam. - Database about plant and crop on grey degraded soils in northern of Vietnam - Final Report: 2013 - Published articles: + Investigate area and top soil properties of grey degraded soils in the North of Vietnam (Science and technology journal of agriculture and rural development, No. 24/2012, pg 19 - 25); + Phosphorus content in the grey degraded soils in northern of Vietnam (Science and technology journal of agriculture and rural development, No. 3 + 4/2013, pg 24 - 30).

Information	Data description
Project name	Soil maps of many other provinces and districts (e.g. Ha Noi, Ha Nam, Phu Tho, Ha Giang, Bac Giang, Nghe An, Yen Bai, Phu Yen, Lam Dong, Dong Nai, Dien Bien, Son La, Lai Chau, Lao Cai, Hoa Binh)
Custodian	Soil genesis and classification Division/Soils and Fertilizers Research Institute/ Director: Nguyen Xuan Lai Le Van Hien street - Duc Thang ward - Bac Tu Liem dist. - Ha Noi, Vietnam
Format	Mapinfo 11.5
Scale	- Provincial level: 1:50,000 to 1:100.000 - District level: 1:10000 to 1:25:000
Content	- No. of soil profiles described to 120 cm depending on each district/province - Soil chemical and physical analyses according to Analysis Standards of Vietnam or Analysis Manual of Soils & Fertilizers Research Institute, 1998 - Soils classified according Vietnam classification system or FAO system
Project reference documents	Final report, different years

Note: Analysis Standards of Vietnam for Soil Analysis Methods: Soil texture: TCVN 8567 - 2010; bulk density: TCVN 6860:2001; porosity: picnometer; pH H_2O and pH KCl: TCVN 5979 - 2007; exchangeable acidity and potential acidity: TCVN 4403 - 2011; Total Organic Carbon: TCVN 8941 - 2011 - Walkley - Black; total N: TCVN 6498 - 1999 - Kjeldahl; total P_2O_5: TCVN 8940 – 2011; total K_2O: TCVN 8660 - 2011; Available P_2O_5: TCVN 8942–2011 – Bray II; available K_2O: TCVN 8662 - 2011; Exchangeable cation: TCVN 8569 - 2010; CEC: TCVN 8568-2010.


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