Foreword

Demands for foods of animal origin are increasing globally, due to increasing population growth, urbanization and income growth. The limits of existing livestock production systems are being approached, if not exceeded, because of increased demands for livestock feeds vis-à-vis availability. Accurate assessments of current and future supplies and demands for livestock feed are needed for national food security policy and planning, as well as the setting of environmentally sustainable stocking rates. National feed resources must be assessed and monitored to provide information that is useful for the development and implementation of appropriate policies that will contribute to the sustainable growth of national livestock sectors.

A wide range of livestock feed situations exists across different countries, environments and livestock production systems, ranging from spatially extensive pastoralist systems to intensive systems consisting of mixtures of crops and livestock, and extremely intensive and landless production systems in which livestock are fed entirely with transported feed. Crop-based livestock systems have the most people, the most livestock, and are the most productive. In these systems, there is a need for continuing assessments of feed resources in support of more efficient and environmentally-friendly land use and improved livelihoods. These are diverse and complex systems with wide arrays of feed sources and types that must be quantified using diverse data from household surveys, agricultural statistics, markets and land use studies. In contrast, spatially extensive systems require livestock movements over large areas of relatively low productivity in environments where crop-based agriculture is not feasible. In these environments, remote-sensing data must be combined with modelling and ground data to monitor forage production over large, heterogeneous and often remote areas.

The aim of this manual is to provide guidance and tools to countries in developing National Feed Assessments (NFAs), based on what has already been learned from current approaches across a wide range of feed situations. Global and country level feed situations are reviewed to highlight the needs for quantitative assessments of livestock feeds in both developed and developing countries. Broad guidelines for the development of NFAs are provided, followed by detailed case studies and descriptions of methodologies that have been implemented in a variety of countries world-wide. The case studies include examples of spatially intensive and spatially extensive production systems, and examples from highly developed as well as developing countries. Based on inputs from a group of experts who met in Rome in November 2010, a set of recommended stepwise procedures is given for implementing NFAs, including procedures for their planning, establishing and updating.

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Acronyms

ACF	Action Contre la Faim
ACU	adult cattle unit
ADDS	Africa Data Dissemination Services
AGB	aboveground biomass
ALMANAC	Agricultural Land Management Alternatives with Numerical Assessment Criteria
ANPP	aboveground net primary productivity
APEX	Agriculture Policy/Environmental Extender Model
ARIMA	auto-regressive integrated moving-average
ARTEMIS	Advanced Research & Technology for Embedded Intelligence and Systems
ASF	animal source food
AUM	animal unit month
AVHRR	Advanced Very High Resolution Radiometer
CMORPH	Climate Prediction Center Morphing Product
CNRIT	Center for Natural Resource Information Technology
CPC	Climate Prediction Center
CR	crop residue
DE	digestible energy
DEM	digital elevation model
DPM	disc pasture meter
DMI	dry matter intake
DMP	dry matter productivity
EDYS	Ecological Dynamics Simulation Model
EVI	enhanced vegetation index
EWS	early warning system
FAO	Food and Agriculture Organization
FCR	feed conversion ratio
FAPAR	fraction of absorbed photosynthetically active radiation
FNIRS	faecal NIRS (near infrared reflectance spectroscopy)

FPAR	fraction of photosynthetically active radiation
GDAS	Global Data Assimilation System
GDP	gross domestic product
GIS	Geographic Information System
GL-CRSP	Global Livestock Collaborative Research Support Program
GLC	global land cover
GPP	gross primary production
GPS	Global Positioning System
GRUMP	Global Rural Urban Mapping Project
GTS	Global Telecommunications System
HANPP	human appropriation of net primary production
HRPT	High Resolution Picture Transmission
HSI	Habitat Suitability Index
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
KRA	key resource area
LARST	Local Application of Remote Sensing Technology
LEAD	Livestock, Environment and Development
LEWS	Livestock Early Warning System
LSWI	Land Surface Water Index
ME	metabolizable energy
MODIS	Moderate Resolution Imaging Spectroradiometer
MSS	multispectral scanner
NAMHEM	National Agency for Meteorology, Hydrology and Environment Monitoring
NAPP	net annual primary production
NASA	National Aeronautics and Space Administration
NASA-GSFC	National Aeronautics and Space Administration - Goddard Space Flight Centre
NCFR	non-conventional feed resource
NDVI	Normalized Difference Vegetation Index
NE	net energy
NFA	National Feed Assessment
NFAS	National Feed Assessment System
NGO	non-governmental organization

NIR	near infrared
NIRS	near infrared reflectance spectroscopy
NOAA	National Oceanic and Atmospheric Administration
NOAA AVHRR	National Oceanic and Atmospheric Administration Advanced Very High Resolution Radiometer
NOAA-HRPT	National Oceanic and Atmospheric Administration - High Rate Picture Transmission
NPP	net primary production
NPV	non-photosynthetic vegetation
PAL	Pathfinder AVHRR Land
PAR	photosynthetically active radiation
PDA	personal digital assistant
PHYGROW	Phytomass Growth Simulator Model
RIAH	Research Institute for Animal Husbandry
SCS	Soil Conservation Service
SLAM	Spatial Livestock Allocation Model
SOM	soil organic matter
SUA	supply utilization account
TOMS	Total Ozone Mapping Spectrometer
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USLE	Universal Soil Loss Equation
VI	vegetation index
VIUPD	vegetation index based on universal pattern decomposition
VPI	Vegetation Productivity Indicator
VPM	Vegetation Photosynthesis Model
WCA	World Census of Agriculture
WEPP	Water Erosion Prediction Project
WMO	World Meteorological Organization

Introduction

WHAT ARE NATIONAL FEED ASSESSMENTS AND NATIONAL FEED ASSESSMENT SYSTEMS?

Simply stated, a *National Feed Assessment (NFA)* is a data- and computation-based analysis of the supplies and demands for livestock feeds in a country, where livestock includes all beef and dairy cattle, sheep, goats, buffalo, swine, equines and poultry. Human foods include a substantial complement of livestock products which are, in turn, derived from a wide variety of plant-based feeds that are consumed by livestock. National agricultural statistics are used to assess food security, but these statistics have often just included statistics for livestock-based food supplies and have fallen short in assessing supplies of plant materials which are needed to support the livestock. An NFA bridges this gap by determining the total quantities of feed available to the livestock relative to the demands of the livestock for feed. Thus, both the supplies and the requirements for feed must be calculated. This is a complex task because livestock feeds are highly diverse and often poorly quantified; they are either not directly measurable commodities or are widely distributed over extensive grasslands and other rangeland environments which are poorly monitored, if at all.

A *National Feed Assessment System (NFAS)* is a complete set of procedures, facilities, tools, personnel, organizations and institutions involved in the collecting, handling and processing of data necessary to calculate and report the supplies of livestock feeds from all sources and for all livestock types in a country. It is a system in the sense that it is more than the mere sum of its parts; it comprises numerous components which interact in an integrated manner to achieve a common outcome – a National Feed Assessment.

WHY DO WE NEED NATIONAL FEED ASSESSMENTS?

Population growth, urbanization and income growth are driving enormous increases in demand for foods of animal origin. The limits of existing livestock production systems are being approached, if not exceeded, due to increasing demands for livestock feeds vis-à-vis availability. The situation is particularly acute in developing countries. The increasing demand for livestock products has far-reaching implications for human well-being, socio-economics, land use, the environment and animal health. Accurate assessments of current and future supplies and demands for livestock feed are needed for national food security policy and planning, as well as the setting of environmentally sustainable stocking rates. Feed resources must be assessed and monitored to provide information for the development and implementation of policies that will contribute to the sustainable growth of national livestock sectors. Assessments will provide information on feed resource availability that will enable optimal policy decisions regarding the use of national feed resources.

Information provided by livestock feed inventories would be of immense utility for policy-makers, government agencies, non-governmental organizations (NGOs), intergovernmental agencies and development agencies in formulating and implementing sustainable livestock development activities and for preparing and coping with climatic variations such

as droughts, floods, severe winter weather events and global climatic change. Spatial and temporal assessments of current and forecasted feed resources, including forage, will assist in disaster management and policy-making. Feed assessments would also inform decisions related to the nature and quantities of commodities, the feed resources that could be traded locally, potential areas for feed markets and feed resources involved in imports and exports. Estimates of feed resources and demands are needed to assess the fractions of food grain that are used for feed.

Although livestock feed shortages have clearly constrained productivity in many countries, the impacts of feed shortages at national levels have been poorly characterized due to the lack of national scale feed assessments. In addition, information on the availability of feed ingredients at the country level will enhance the efficiency and profitability of the animal feed industry and assist researchers to formulate sustainable feeding strategies. Such information would also be useful for determining the input-output relations for countries such as the estimation of edible protein outputs versus protein inputs. Estimates of feed resources would also improve the accuracy of assessments of the environmental impacts of livestock resulting from land use transformations as well greenhouse gas emissions and element fluxes (e.g. nitrogen) associated with livestock production. Production and consumption of feeds would significantly affect the potential of ecosystems to sequester carbon. Country-level feed balances based on feed inventory data will facilitate planning within the livestock industry, for example in determining how many animals can be supported or produced based on existing feed resources, and in identifying what feed resources would and could be developed to achieve production objectives. Such efforts will, in turn, translate into enhanced food security balanced with environmental sustainability.

There is a wide spectrum of livestock feed situations globally and within individual countries, varying from intensive use of crop-based feeds and pastures to spatially extensive use of grasslands and rangelands. Land availability and water are key constraints on the production of alternative feeds for ruminants in the most intensive systems. A structured approach to planning for this increase in demand will be necessary if demand is to be met cost-effectively, with minimal social disruption and minimal environmental impacts. In arid and semi-arid regions, pastoralists graze their livestock in spatially extensive grazing systems characterized by large-scale seasonal movements. Livestock forage production is highly limited by rainfall, which is spatially and temporally variable. Knowledge of forage biomass availabilities and distributions can assist pastoralists in determining whether to move, buy or sell animals, and assess the level of risk for decision-making. Feed assessments are needed to provide useful information for food aid organizations, pastoralists, governments and development agencies.

The prospect of increasing feed demands raises the serious question of how these additional livestock feed requirements will be provided. Systematic approaches for accurately assessing livestock feed supplies are relatively undeveloped compared with long-standing programmes that inventory agricultural productivity (e.g. FAO, 1994, 2010). Furthermore, the quantification of livestock feeds has proved to be more challenging than the quantification of total crop production for a number of reasons. Data needs and complexities increase with the addition of another trophic level. Data are needed for the production of numerous derived feedstuffs and the availabilities of forage for livestock. Many crop residues and by-

products used for forage are not quantified because they have no direct market value. Many additional, but poorly quantified factors, constrain access to forage in spatially extensive rangelands and grasslands.

Recently, the Livestock Data Innovation in Africa Project administered an online survey among livestock stakeholders to identify core livestock domains/areas for which livestock information is demanded (Pica-Ciamarra *et al.,* 2012). The survey had 641 respondents. Within governments livestock data and indicators are used for three main purposes, including policy and planning (44 percent), development projects (33 percent) and research (30 percent). NGOs/Donors/International Organizations use data/indicators primarily to design and implement development projects (31 percent); private companies to formulate investments (76 percent); researchers for research purpose (67 percent) and to formulate and implement development projects (39 percent). Out of 15 different livestock data types, data on livestock feeds was ranked fourth in importance, behind animal health, meat production, and livestock population. Milk production was fifth. Respondents also ranked various data types according to needs for improvements in data quantity and quality. Livestock feed data was ranked third in needs for improved data.

Based on an assessment of the current global livestock feed situation, as presented in this Manual, it is clear that global feed resources, especially those which will support the rapidly growing, intensive production systems of the developing world, must be assessed and monitored to provide information that is useful for the development and implementation of appropriate policies that will contribute to the sustainable growth of the global livestock sector. Assessments will provide information on feed resource availabilities that will enable optimal policy decisions regarding the use of these resources. The assessments should enhance the development of optimal feeding strategies and thus food security, the ability to cope with emergency feed shortage situations, the ability to provide input data into country level food input-output analyses, and the capability to assess environmental impacts of livestock.

A wide range of livestock feed situations exists across different countries, environments and livestock production systems (Thornton *et al.,* 2002, 2003, 2006). An overarching gradient exists from spatially extensive pastoralist systems to increasingly intensive systems consisting of mixtures of crops and livestock, and to extremely intensive and landless production systems in which livestock are fed entirely with transported feed. The spatially extensive systems are typically found in arid and semi-arid environments, or in environments that are thermally limited with short growing seasons.

Spatially extensive systems require livestock movements over large areas of relatively low productivity in environments where crop-based agriculture is not feasible. It has been difficult to assess forage availability in such environments due to the difficulty of forage production monitoring over large, heterogeneous and often remote areas. Moreover, forage production is an insufficient measure of forage availability in such environments because availability is constrained by drinking water, topography and other factors that affect livestock movements. Temporal variability of feed availability in such environments is highly important, as feed availability varies with seasons and with variations in precipitation, snow cover, and water availability. Food security in these environments is often jeopardized by droughts or severe winter weather conditions. These systems are being altered by increasing competition for land, sedentarization and restrictions on mobility. In such environments,

there is a need for livestock feed assessments that can quantify forage biomass over large areas while accounting for temporal variability and constraints on feed availability.

Crop-based livestock systems have the most people, the most livestock, and are the most productive. Crop-based systems are facing increasing demands for food, especially animal source foods and increasing human and livestock populations. As such, they are dynamic. Also, crop-based livestock systems can be in direct competition for land where crops are being grown for human food production. Increasingly, livestock systems are making use of crop residues and other agricultural by-products which are often difficult to quantify. These are diverse and complex systems with a wide range of feed sources and types. The intensity of land and resource use in such systems presents challenges for environmental sustainability. In these systems, there is a need for continuing assessments of feed resources in support of more efficient and environmentally-friendly land-use and improved livelihoods.

Spatially extensive and crop-based systems are both dynamic, and it will be important for feed assessments to capture trends. Feed assessments will only be useful if they address the dynamism of the systems themselves (i.e. modes of operation), as well as the dynamism of feed production and utilization. Capturing trends will, therefore, be very important, both looking back and, most importantly, anticipating change and its implications. Consequently, an important output of a feed assessment system will be a trend analysis, synthesizing results of the current assessment compared with past assessments. Observed trends must be analysed and explained. Other changes that are caused by unpredicted driving forces should also be identified and assessed.

WHO WILL DEVELOP NATIONAL FEED ASSESSMENT SYSTEMS?

The development of a National Feed Assessment System (NFAS) must include people with expertise in a wide variety of relevant subject matter regarding livestock production systems in a broad range of environments and settings, as well as people with expertise in the procedural and organizational aspects of implementing national-scale database systems. Technical expertise will be needed in various aspects of livestock and feed production systems, agriculture, grassland and rangeland ecology, agricultural statistics, and spatial databases. Stakeholders who are affected by various aspects of livestock feed production activities and feed availabilities must also be involved, including livestock producers, pastoralists, feed producers, NGOs, as well as government ministries, researchers and academicians. Stakeholders and partners will be central in the implementation of a NFAS because they will undoubtedly play a variety of important roles in its ongoing operation and utilization. They may, for example, be data providers or facilitators of data sources. They will also play a role in its institutionalization.

Task forces or working groups can be formed from the pool of people with this wide range of expertise and interests. This will include: a) people with skills and knowledge in agricultural resource statistics and agricultural systems analysis; b) people with extensive knowledge of rangeland and crop-based livestock production systems, and animal nutrition; c) people with technical capabilities in geographic information system (GIS) analysis, remote sensing, ecological and agricultural modelling, database design, statistics, sampling and surveys; d) people with multi-disciplinary expertise, that is, with broad, large-picture, integrative, systems-level perspectives; e) people from farmers' or livestock keepers' associations

and pastoral NGOs; f) people from government ministries overseeing agriculture, land use and the environment; g) people from the private sector who are involved in feed production; h) people from NGOs and research institutions who have relevant experience; and i) proponents, including individuals, who are in a position to push the implementation forward with respect to government institutions and other potential end user groups.

An institutional framework must be created. The institutional framework of the NFAS may comprise a single NFAS organization or a coalition of organizations with diverse roles and responsibilities. The institutional framework will be the backbone of the NFAS. It will ensure that there are mechanisms to maintain the necessary infrastructure for its continued application. Institutionalization will require: a) the identification of the national implementing partner; b) the establishment of an institutionalized coordinating team at a national or possibly regional level: c) the establishment of a state and/or central government budget line to support the system, along with capabilities for the necessary mobilization of resources, capital and recurrent expenditures; and d) the establishment of a regional training programme for staff who will implement the system, as well as end users who will use the outputs of the NFAS.

Members of governments and research organizations who wish to establish national feed assessment systems will likely seek guidance on the technical issues and procedural aspects involved. This document aims to provide such guidance.

Aim and structure of this manual – a road map

The aim of this document is to provide guidance to countries in developing NFAs, based on lessons learned from current approaches across a wide range of feed situations. Although feed inventories are the primary components of NFAs, the concept of an assessment is broader because it considers the causes and consequences of variability in feed supplies, balances between feed supplies and requirements, and other implications of feed quantity and quality.

The document has three major sections. Sections I and II may suffice for most readers; those interested in more detail can refer to Section III.

Section I provides a broad perspective of the current state of knowledge on the livestock feed situation. Chapter 1 sets the stage by providing an overview of global trends in livestock-based foods and Chapter 2 continues with an overview of subsequent growth in livestock feed requirements. Chapter 3 summarizes assessments of the livestock feed situations for a number of country, regional and global case studies, most of which are described in detail in subsequent chapters of this document (Chapters 8–13).

Section II contains a synthetic overview of methodologies and guidelines for implementing NFAs. It is suggested that the reader refers to this Section before going to Section III. Chapter 4 covers approaches for calculating growth in livestock feed requirements, methods for assessing feed supplies in crop-based and spatially extensive grazing systems, tools specifically utilized in rangeland systems, methods for assessing feed balances, data base methods and data sources. A section on environmental considerations is also included, given that any assessments of feed availabilities are contingent on potential interactions with alternative land uses and impacts on ecosystem services. Chapter 5 provides stepwise guidelines for the procedural and organizational aspects of planning, establishing and updating a National Feed Assessment System (NFAS). These recommended procedures for implementing a NFAS are based on inputs from a group of experts who met in Rome in November 2010.

Section III contains the detailed descriptions of the case studies summarized in Chapter 3 and the methodologies described in Chapter 5. The case studies are specific examples that could assist countries desiring to establish a NFAS. Methodologies are described, along with example implementation, data inputs and NFAS outputs. Chapter 7 describes an approach for calculating the growth in demands for livestock-based food and livestock feeds at national through global levels. Chapters 8–13 are in-depth case studies of recent approaches to assessing livestock feed situations in a wide variety of countries or regions with markedly differing socio-economic and biophysical environments. The Switzerland case study is an example of a NFAS in a highly developed country with well-developed agricultural statistics and data bases, and a preponderance of well-defined crop-based feeds but also with important pasture resources. The India case study demonstrates the challenge of assessing

livestock feeds in a highly diverse environment with less developed national agricultural statistics and databases. India contains a very wide variety of mixed crop-livestock systems and highly intensive utilization of all forms of potential livestock feeds, many of which are difficult to quantify because they are normally not included in national agricultural statistics. These two NFASs are especially capable of assessing livestock feeds from crops or mixed crop-livestock production systems.

These are followed by four examples from "spatially extensive" systems in Africa and Asia where national agricultural statistics would be of little use due to the primary dependence on non-crop-based resources in grasslands, savannahs and other types of rangelands. In these systems the only source of data over such vast areas is from satellite-based sensors orbiting high above the Earth's surface, Chapter 14 presents a relatively detailed methodology for calculating livestock feed balances, the central part of which is the calculation of livestock feed requirements based on livestock energy requirements, digestive efficiencies and the energetic characteristics of feed sources. Chapter 15 describes a comprehensive ecosystem modelling approach that can be applied to spatially heterogeneous and extensive livestock systems. The ecosystem modelling approach is the most demanding, but it also integrates the full range of factors involved in the livestock feed assessment, including calculations of spatially and temporally varying feed availabilities along with calculations of livestock feed requirements and actual intake rates on various parts of the landscape. The modelling approach is also prognostic, in the sense that predictions can be made on the basis of changes in climatic and other environmental conditions. Chapter 16 is a detailed description of methodologies for forage evaluation in grasslands and rangelands, from field-based approaches for measuring forage quantity and quality, to systems which utilize satellite and weather data over regional spatial scales, and to ecosystem modelling approaches.