SP3: Assessment of Crop-Specific Carbon and Mineral Element Fluxes for Sustainable Soil Fertility Management in Horticultural Productions Systems

Project Partners:

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I. Objectives

Overall aim of the sub-project is provide knowledge on the current status of soil fertility management, and identification of possible constraints for vegetable production in the peri-urban area of Nairobi due to mineral nutrients, soil organic matter contents and heavy metals. Data will be collected for various African indigenous vegetables (AIV) including amaranth, African night shade, African kale, spider plant and cowpea, and compared to data from maize as a standard species. The data will form a basis for the development of a catalogue of recommendations to improve soil fertility, nutrient efficiency and vegetable nutritional quality in vegetable production systems through agronomic measures and will be of major **relevance** to actors and decision makers of VCs (outputs 1-3). Specifically, the project will address three **research goals**:

1) Analysis of the current status of nutrient management and of crop-specific mineral nutrient requirements

To achieve this object, the variability of soil nutrient availability and associated plant nutrient status, and species-specific nutrient balances will be assessed for AIV at the scale of farms and individual fields. Root traits related to nutrient acquisition from soil, and species-specific responses to differences in soil nutrient availability will be identified in field and pot experiments on research station. This knowledge will provide a basis for the generation of integrated nutrient management strategies for AIV for the purpose of increasing yields (outputs 1, 2 and 3). Nutrient balances and management strongly impact on biodiversity, soil fertility, soil carbon sequestration, and greenhouse gas emissions both, via direct effects e.g., of reactive nitrogen compounds, and via indirect effects on plant productivity and thus, competition between agricultural and natural landscapes (DeFries and Rosenzweig, 2010). Therefore, the project will also contribute to the assessment of ecological sustainability of vegetable production systems (Output 4).

2) Analysis of the current status of soil organic matter (SOM) management and of crop-specific effects on SOM content

To achieve this object, the variability of SOM contents and causes underlying this variability will be assessed at the scale of farms and individual fields. The mass and composition of plant-derived organic carbon (C) input from above-ground and below-ground organs into the soil will be measured, and humification coefficients of plant-derived C will be quantified. These data will provide a basis for the generation of integrated soil fertility management strategies for AIV for the purposes of increasing yields (outputs 1, 2 and 3), and the assessment of ecological sustainability of vegetable production systems (Output 4).

3) Analysis of the current status and sources of heavy metal (HM) contamination of vegetables, and of crop-specific plant traits regulating HM contamination

To achieve this object, HM availability in soil and irrigation water will be measured at the scale of individual fields and related to contents in edible organs of AIV. Surface contamination and internal accumulation of samples taken in fields, stores and markets will be compared to identify sources of HM pollution in urban and peri-urban horticultural systems (Output 2). Species-specific pathways of HM contamination and plant traits regulating HM accumulation will be identified in field and pot experiments. This knowledge will provide a basis for the development of guidelines to prevent excessive exposure of consumers with toxic metals, and thus will contribute to improve nutritional value and quality of AIV (Output 1).

II. State of knowledge

Poor soil fertility and associated nutrient limitation for crop growth are important constraints in smallholder farming systems in sub-Saharan Africa (sSA) (Sanchez 2002). Recent nutrient balances for cropland soils at global and national scales show an overall deficit of P in countries of eastern sSA (MacDonald et al. 2011), and of N for sSA (Liu et al. 2010) and Western Kenya (Vitousek et al. 2009). However, nutrient balances considerably differ at the scale of villages, farms and individual fields within farms depending on socio-economic and biophysical conditions, e.g., the wealth status of farmers (Haileslassie et al. 2007), production strategy (Berkhout et al. 2011), soil management (Esilaba et al. 2005) and crop species (Diogo/Buerkert/Schlecht 2010). In urban and peri-urban agriculture, nutrient balances can be positive (Sangare et al. 2012), and in urban areas of sSA eutrophication is an increasing problem (Nyenje et al. 2010). Thus, it is a principal challenge to optimise the allocation of scarce nutrient resources among farms and fields within farms to avoid soil fertility loss associated with negative nutrient balances (soil mining), and low nutrient efficiency and environmental pollution associated with positive nutrient balances.

For appropriate nutrient management information is needed on crop-specific nutrient requirements, which depend on nutrient composition, and the ability for nutrient acquisition from soil. In comparison to grain crops like millet, vegetable crops are often characterized by high K and low N and P concentrations in biomass (Diogo/Buerkert/Schlecht. 2010), whereby large differences of nutrient composition exist among vegetable species (Khai/Ha/Öborn 2007). For AIV little is known about morphological and physiological roots traits regulating the spatial and chemical nutrient availability in the rhizosphere (Engels et al., 2000).

SOM is a key element of agricultural soil quality and fertility (Moebius-Clune et al. 2011). Stable SOM increases the soil capacity for nutrient and water storage, thus, reducing nutrient leaching. Labile SOM contributes to nourishment of heterotrophic soil organisms. Their activity regulates aggregate stability, and thus reduces nutrient losses through surface run-off and soil erosion. Labile SOM is a source of plant nutrients which are released during mineralization. Furthermore soluble organic compounds formed during SOM degradation increase plant availability of inorganic soil nutrients (Marschner/Marschner 2012).

In agricultural soils, SOM content is strongly influenced by climate, soil factors, and agronomic measures including application of organic fertilizers, soil tillage, and cropping system (Bationo et al. 2007). Many smallholder farming systems in sSA are characterized by large variability of SOM content among different fields within a farm (Giller et al. 2011).

Little is known about crop-specific effects on SOM. In principal crop-specific effects on SOM can be due to soil management, e.g., farmer’s strategy to allocate scarce resources to different crops (Giller et al. 2011), and biologically-based differences in crop-related C input into soil. Large amounts of organic C are imported into soil from above-ground through litter fall during the growing period and plant residues, and from below-ground through rhizodeposition and roots remaining in soil after harvest (Jones/Nguyen/Finley 2009). It has been found that SOM content is positively correlated with input of plant-derived organic C (Di Bene et al. 2011). In a recent study of Chinese vegetable production systems, large differences among species in above-ground C input into soil were detected (Jia/Ma/Xiong 2012). The effect of plant-derived organic C on SOM is not only dependent on the mass but also biochemical quality of plant materials (Palm et al. 2001).

Human mineral malnutrition contributes 3 of the 20 most important health risks world-wide (Stein 2010), and is a serious problem in sSA (Caulfield et al. 2006). Vegetables constitute an important dietary source for essential microelements like Fe and Zn (Frossard et al. 2000) and for toxic HM like Cd and Pb (Sharma/Agrawal/Marshall 2007).

Plants can be contaminated with HM via different pathways, including uptake from soil by roots and subsequent translocation to edible plant organs via xylem and phloem, uptake from atmosphere by aboveground plant organs, and surface contamination by dust and soil. For uptake from soil, total HM content and bioavailability of HM play an important role. In urban and peri-urban vegetable production systems, soil content is often increased e.g., through wastewater irrigation (Gweyi-Onyango/Osei-Kwarteng 2011), whereby this practice may particularly increase bioavailable HM fractions in soil (Abdu/Agbenin/Buerkert 2012). For uptake of HM from atmosphere and surface contamination, transportation and marketing systems of vegetables play a significant role (Sharma/Agrawal/Marshall 2009).
HM uptake and accumulation may strongly vary among tropical vegetable species which are grown on soils polluted by sewage sludge (Nabulo/Black/Young 2011), wastewater irrigation (Abdu/Agbenin/Buerkert 2011) or river irrigation (Weldegebriel/Chandravanshi/Wondimu 2012). Depending on the plant contamination pathway, HM accumulation may be regulated by root traits (e.g., root depth distribution, modification of chemical soil properties in the rhizosphere) or leaf traits (e.g., leaf area, structure and composition of epidermis).

III. Detailed description of work plan

a. Activity/milestone table

Activity	Milestone	Timeframe	Resp. partner
NM1: Measurement of SOM content, soil nutrient and HM availability and corresponding mineral element concentrations of crop species on farmers fields	Data base of soil fertility variability within and among farms and identification of plant nutritional constraints to vegetable production	01-2013 to 12-2015	BU, KU, EU, HUB
NM2: In-depth interviews with farmers and extension workers	Data base on locally existing knowledge on soil fertility, and strategies for resource allocation	01-2013 to 06-2014	BU, KU, EU, HUB
NM3: Field-specific measurement of nutrient input and output on farmers fields	Identification of nutrient efficiency at field and farm level	01-2013 to 06-2015	EU, BU, KU, HUB
NM4: Measurement of crop-specific nutrient requirement and responses to nutrient supply in pot and field experiments	Identification of critical nutrient levels in soil and plants leading to yield and quality losses	06-2014 to 01-2017	EU, BU, KU, HUB
NM5: Field- and crop-specific measurement of organic matter input via fertilizers and plants, and assessment of humification coefficients of C sources in field litter bag studies, and under controlled conditions	Data base for crop- and site-specific requirements for organic fertilizer supply to maintain sufficient level of SOM	01-2014 to 01-2017	BU, KU, EU, HUB
NM6: Measurement of HM input and output on farmers fields, and concentrations in vegetables at various points from field to market	Identification of major sources and pathways of HM contamination as basis for recommendations to reduce concentrations in edible organs	01-2015 to 07-2017	KU, BU, EU, HUB
NM7:Measurement of HM concentrations in different plant organs and rhizosphere soil, and of root distribution in pot and field experiments	Identification of crop-specific root and shoot traits regulating HM contamination as basis for recommendations for culture on slightly polluted soils	06-2015 to 10-2017	KU, BU, EU, HUB

IV. Utilization of results

The data and knowledge acquired in this subproject will serve as basis for catalogues of options and locally tailored recommendations for integrated SOM and nutrient management in horticultural production systems, and avoidance of HM hazard of vegetable consumers. Development and compilation of recommendations will need additional input by socio-economic projects dealing with institutional and financial constraints, and the role of women in horticultural production systems. Furthermore, input is needed by various stakeholders including farmers, extension service workers and local researchers. The catalogue of options and recommendations will support farmers, extension service workers, development agencies and politicians in their efforts for sustainable vegetable production and increase food safety.Results of this subproject will be published in scientific journals, and will form a basis for future studies. Specifically, the data on crop-specific shoot and root traits involved in mineral acquisition from soil and organic C input into soil can be used for quantification of C and mineral fluxes with mechanistic models, and for modelling of water- and nutrient-driven growth.

V. Internal division of labor and cooperation with other sub-projects

Internal division of labor: All activities of this subproject are collectively planned by all 4 project partners. All project partners will be integrated in the supervision of PhD- and Master-students and participate in data analysis and publication.

Cooperation with sub-project Water Use Efficiency (WUE): SOM content is an important factor regulating water infiltration into soil and soil water holding capacity, and thus, soil characteristics related to water use efficiency. Therefore, data on SOM content of farmers' fields will contribute to the assessment of water use efficiency in subproject WUE. Root depth distribution in soil is an important factor regulating availability of soil water for plants. Data on crop-specific root distribution collected in this project will be used for modelling and complement the assessment of WUE.

Cooperation with sub-project "Health": Essential and toxic minerals contribute to the nutritional value of vegetables. Thus, data on crop-specific concentrations of micro-elements (Fe, Zn) and HM collected in this project will complement the assessment of nutritional quality of vegetables in sub-project "Health".Plant content of bioactive compounds is influenced by plant nutritional status. Plant samples of African kale from farmer´s fields and N- and S-fertilization experiments conducted in this project will be analysed for glucosinolates in sub-project "Health" to assess plant nutritional constraints for biosynthesis of glucosinolates.

Cooperation with socio-economic projects on socio-economic constraints: In this project, data will be collected from farms differing in wealth status to evaluate the relationship between socio-economic factors and the strategy of soil fertility management. Selection of farms, conductance of interviews, and evaluation of data will be done in cooperation with socio-economic projects.