SP1: Increasing Water Use Efficiency in African Leafy Vegetable Production Systems

Project partners:

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I. Objectives

Water conserving irrigation and cropping technologies such as drip irrigation, partial root zone drying, regulated deficit irrigation or mulching are important means to sustainably produce high quality vegetables under water-limited conditions. The farmers may be aware of these technologies, but have not adapted them for numerous reasons. Participatory approaches need to be employed to increase adoption. This should involve evaluation for technical optimization and farm demonstrations.

The **overall objective** of this study is to develop technologies to reduce water use and improve water supply for high yield and high quality. This knowledge will benefit decision makers and actors of value chains of indigenous vegetables to improve water use efficiency (outputs 1-3) Specifically, five **research objectives** are focused on:

- Development of water conserving cropping technologies. It is hypothesized that through reduced soil tillage and mulching, unproductive evaporation can be reduced-thereby yield is increased and produce quality improved. It is further hypothesized that there are thresholds for water deficits below which yield and quality are not negatively affected but significant water savings are possible.
- Determination of water use parameters as a basis for irrigation scheduling. It is hypothesized that water consumption of a crop can be related to that of a reference crop by a genotype and development-dependent crop coefficient kc. It is further hypothesized that development-dependent effect can be estimated based on thermal time (temperature sum).
- Evaluation of genetic diversity in drought tolerance and compositional changes. It is hypothesized that genotypic differences exist within species of ALVs regarding the major water-dependent processes like leaf expansion, root growth, stomatal conductance, and photosynthesis.
- Development of a cropping systems model for planning and evaluation. This model will describe the major processes of water transport and crop growth. It will be parameterized and tested with experimental data. It will be used to systematically explore the effects of environmental conditions and cropping practices on crop growth and water use to identify optimal irrigation strategies.
- Development of improved irrigation strategies based on model results and experts' preferences. A synthesis will be sought from results of the model study and recommendations of experts.

II. State of knowledge

The availability of water for crop production is one of the major limiting factors to food production worldwide. Global crop water consumption is expected to increase by 0.7% per year, and the resulting scarcities are expected to increasingly constrain food production growth and food security (Rosegrant/Ringler/Zhu 2009). It is therefore not surprising that out of the „top 100 questions of importance to the future of global agriculture" fourteen explicitely address issues of water and drought (Pretty et al. 2010).

African Leafy Vegetables (ALVs) are important sources of human nutrients and household incomes. This has led to promotion of their production and consumption. In Kenya, there was an increase by 213% between 2001 and 2006 (Irungu 2007). With this continuing rise in demand of ALVs becomes increasingly professionalized in peri-urban areas which are often characterized by shortage of water between rainy seasons (Jaetzold et al., 2007). This calls for techniques that utilize the available water more efficiently.

The scope for increasing water use efficiency (WUE) is considered large (Rosegrant/Ringler/Zhu 2009). Basically, WUE can be increased by reducing unproductive water losses through evaporation barriers like mulches or improved irrigation techniques like drip irrigation, or by better meeting the the physiological requirements of crops.

Experiments comparing conventional surface or overhead irrigation with drip irrigation frequently show higher yields and water use efficiencies in drip-irrigated crops (e.g. Tiwari/Singh/Mal (2003) for cabbage). Reasons may be manyfold, but in addition to better temporal control reducing unproductive evaporation through decreasing the wetted surface is obvious. Use of plastic mulches has been shown to increase productivity and water use efficiency of field crops in water-limited environments (Zegada-Lizarazu and Berliner 2011; Zhou et al. 2011).

Deficit irrigation (DI) and partial rootzone drying (PRD) are a water-saving irrigation practices where water supply is kept below the amount necessary for maximum growth (DI) or water is applied only to a part, usually one side, of the plant's root system, while the other part remains unirrigated until the next irrigation application, when the other half of the root system is watered (PRD). The mechanism of DI and PRD is thought to be through induction of ABA signaling in roots, which may lead to partial stomatal closure and hence reduced transpiration (Plauborg et al. 2010) and less oxidative stress damage in roots under water deficit (Hu et al. 2010). DI and PRD have been applied to many crop species. In potato and tomato, use of DI and PRD irrigation strategies reduced water use by 20–30% with no significant yield loss and increased irrigation water use efficiency by 10-40% (Jensen et al. 2010; Shahnazari et al. 2007;). Similarly, deficit irrigation, a practice where water supply is kept below the amount necessary for maximum growth, may increase WUE.

Matching water supply to plant requirements needs information on the course of crop evapotranspiration. The United Nations' Food and Agriculture Organisation has developed a method to calculate the crop's water use by multiplying the reference ETo by a crop coefficient Kc (Allen et al 1998). Crop coefficients have been determined and are used for scheduling of irrigation in major crops, e.g. in Canada (Van der Gulik and Nyvall, 2001) or Carlifornia, where an an MS Excel based tool was developed to assist in irrigation management of crops (Snyder et al. 2007). Other studies have developed Kc values for tomato, strawberry (Clark et al. 1996), blueberries (Haman et al. 1997) and melon (Shukla et al. 2007). Kc values mainly characterize canopy size and structure, thus reflecting leaf area index (LAI) and ground cover. However, Kc values are also influenced by irrigation method or mulching practice and differ between genotypes. Kc values of ALVs have not yet been determined and no information exists on the genetic variation of this important plant characteristic.

III. Detailed description of work plan

a. Planned milestones of the intervention

Activity	Milestone	Time frame	Responsible partners
W1: *To develop water conserving cropping technologies:* A series of four field experiments, two between and two in the rainy seasons, will be conducted on the experimental site of JKUAT within the first 18 months. Spider plant and African kale will be grown at six water management strategies (conventional irrigation, drip irrigation, mulch, regulated deficit irrigation, partial root zone drying, reduced tillage) with	M1: Experiments on developing water saving strategies completed (month 18) M2: Experiments on testing water saving strategies completed	01.2013-12.2015	LUH, JKUAT

four replications. During months 19-30, evaluation experiments will be conducted on farmers' fields. These experiments will be done in two sites, one in a water deficit zone that produces vegetables and one site in the peri-urban zone engaged in commercial vegetable production. These are tentatively Kibwezi and Kiambu, respectively. Professional experts (farmers, farm advisers) will be incorporated to advise on conventional irrigation techniques and comment on experimental results.	(months 30) M3: Publications on water saving management strategies written (month 36)		
W2: *To determine water use parameters as a basis for irrigation scheduling*: The study will be carried at the Experimental farm of JKUAT. Evapotranspiration from cropped areas (Etc) shall be estimated using drainage lysimeters and soil water measurement. Both open field and high tunnels will be included. African nightshade, spider plant, Ethiopian kale will be grown at different levels of irrigation. Plant growth and water uptake and reference evapotranspiration based on climatic data will be calculated. Kc values for vegetables shall be computed by dividing the estimated ETc by reference evapotranspiration (ETo).	M4: Experiments to determine Kc values completed (month 21) M5: Kc-values published (month 24)	01.2013-12.2015	LUH, JKUAT
W3: *To evaluate genetic diversity in drought tolerance and compositional changes*: Two experiments, each one considered one replication, will be conducted to evaluate ca. 150 - 200 lines of spiderplant under stress and non-stress conditions. Leaf and growth, total plant dry matter and physiological parameters like stomatal conductance will be determined.	M6: Experiments on genetic diversity completed (month 42) M7: Publication on genetic diversity written (month 48)	01.2014-12.2016	LUH, JKUAT
W4: *To develop a cropping systems model for planning and evaluation:* Based on the experimental data models will be constructed to simulate crop growth and water flux processes based on environmental parameters. Model crops are spider plant and African kale. After model evaluation using experimental data of Tasks 1 and 2, models will be used to identify optimal practices of water management.	M8: Crop water model written (month 39) M9: Crop water model publication written (month 42) M10: Manuscript on model-based management strategies written (month 45)	01.2014-12.2016	LUH, JKUAT
W5: To *develop improved irrigation strategies based on model results and experts' preferences.* Model results, Kc values and experts' comments will be used to develop guidelines practical for irrigation of vegetables. These guidelines address practical farmers and will be published on the program's website.	M11: Guidelines published (month 48)	01.2014-12.2016	LUH, JKUAT

Table 2: Project activity/milestone table

V. Utilization of results

The project will create publications on the relationships between water supply and crop growth which will be of fundamental scientific interest. These publications will appear in peer-reviewed international journals. The international, but particularly the African scientific community will benefit. Recommendations of specific irrigation practices will be relevant for farmers and advisors. These will be made available to the public through our website and articles in applied journals. Plant breeders will benefit from the evaluation of genotypic variation. Additionally workshop with farmers will be organized to sensitize the farmers about the technologies.

VI. Internal division of labour and cooperation with other subprojects/ third parties

The entire project will be the basis for two PhD thesis written by two African PhD students. PhD student 1 will be responsible for tasks 1 and 3, PhD student 2 will perform tasks 2 and 4. Task 5 will be assigned to both PhD students jointly.

Experiments for development and testing of improved water management practices and for determination of Kc values will be conducted in close cooperation with the project on carbon and nutrient fluxes. This way, a complete picture of water, carbon and nutrient fluxes together with plant growth will be obtained. This will also allow the analysis of the effects of irrigation practices on nutrient losses.

The experiment on genetic diversity will be conducted in collaboration with the breeding/seed multiplication project for genotypic characterization and with the nutrition project for determination of bioactive substances, especially glucosinolates.

There will also be collaboration with Kenya Agricultural Research Institute (KARI) and Ministry of Agriculture Extension during field experiments and workshops with farmers