Water-Smart Agriculture through Integrated Soil and Water Management: The Uganda Experience

Agriculture is a major source of livelihood for more than 80% of Uganda's population (Mundi, 2014). However, water shortage and soil degradation constraints, among other things, are increasingly hampering smallholder farmers' activities, thereby threatening agricultural sustainability. This is evidenced through rainfall uncertainty, increasing frequency of droughts, extreme weather events, changing growing seasons and soil exhaustion (Ssali, 2002). These challenges result in frequent crop failures, leaving many farmers vulnerable.

With most agriculture in Uganda being rainfed, there is increased risk of crop failure due to extreme weather events (Mubiru *et al.,* 2012). Water-smart agriculture (WaSA) addresses this risk and builds farmers'' resilience by combining rainfed farming with sustainable, small-scale soil and water management (http://wle.cgiar.org/blog/2014/07/30/water-smart-agriculture-initiative-east-africa).

This review presents examples of WaSA practices that have worked in Uganda through integrated soil and water management.

Integrated soil and water management and water-smart agriculture

Integrated soil and water management (ISWM) is the use of soil and water management practices that enable users to maximize economic and social benefits from soil and water resources, while maintaining or enhancing their ecological support functions (FAO, 2009).

ISWM ensures that productivity and ecological integrity of soil resources are maintained over time. It is key for improving land resource productivity and resilience and is critical in coping with devastating effects of climate change and environmental degradation.

Soil organic matter, especially the more stable humus, increases the soil's capacity to store water (Bot and Benites, 2005). Practices that increase soil organic carbon content will contribute to WaSA. These practices keep the soils productive, have a rich biodiversity, require less chemical inputs, and sustain vital ecosystem functions.

Soil productivity and water-smart agriculture

Soil productivity depends on the soil's physical, chemical, and biological properties. Soil properties most important for WaSA include texture, structure, organic matter content, nutrient content, soil organisms, pH, and cation exchange capacity.

These properties influence the soil's ability to retain water and nutrients. Degraded soils are vulnerable to moisture stress due to serious loss of soil organic matter, nutrients, biodiversity, unfavorable soil physical properties (e.g., compaction), and high soil erosion rates.

Steps in managing soils for water-smart agriculture

Assess soil status

Knowing the soil status and condition helps in decisionmaking regarding suitable management practices for WaSA. The process involves field soil assessment and survey supplemented by laboratory testing to determine critical soil properties (texture, structure, water-holding capacity) crucial to their sustainable management. Sandy soils retain less moisture and nutrients, and therefore, can be managed by providing water, organic matter, and fertilizers.

Local field indicators can also be used to assess the nature of soils. Studies in Masaka District show that farmers use indicator plants/weeds to identify good soils from poor ones. Weeds such as Katabuteme, Sekoteka, Kafumbe, and Lusenke indicate fertile soils, while black jack, couch grass, Kakuuku, Eteete, and Muwugulaomunene grow on poor soils. Similarly, crops such as banana do well on good soils, while mango can grow on poor soils (Tenywa *et al.,* 2014).

Control soil erosion

Soil erosion is a serious land degradation process, particularly for cultivated land on moderate to steep slopes and areas with sparse ground vegetative cover. Runoff and soil erosion can be reduced using mechanical, biological, or a combination of methods (Magunda and Tenywa, 2001).

Mechanical means comprise soil and water conservation structures (terraces, contour bunds, stone bunds, etc.). Terraces are made by digging a trench 60 cm wide along the contour and throwing the soil upslope (or downslope) to form an embankment. This, in turn, reduces slope length, and hence soil erosion from steep cropland (Thomas and Biamah, 1991). The soil bund retains water and thereby safeguards crop yield even during drought. The bunds may be reinforced by planting grass or agro-forestry trees on them, to make them more stable.

Contour bunds are constructed by excavating a channel and creating a small ridge on the downhill side (Mati, 2005). They drain excess runoff from steep cultivated lands. They may be reinforced using grass or agro-forestry trees to make them more stable. In Rakai District, runoff, and soil and nutrient loss decreased significantly following construction of contour bunds on banana, coffee, annual crop, and rangeland fields (Majaliwa *et al.,* 2004). Construction of contour bunds on rangeland resulted in higher biomass, ground cover, and species diversity (Table 1).

***Table 1**. Effect of contour bunds on production of a degraded rangeland (2 years after).*

Property	No contour bunds	With contour bunds
Soil physical and chemical properties		Improved
Rangeland biomass (t/ha)	7.1	27.2
Ground cover (%)	51.0	86.1
Plant species diversity (Shannon index)	3.93	4.46

Stone lines are structures where stones are arranged in lines across the slope to form a strong wall. The stones slow down the speed of runoff water, filter it, and spread the water across the field, allowing it to infiltrate into the soil and reduce soil erosion (Critchley and Siegert, 1991). Stone lines are commonly spaced about 15-30 m apart, with narrower spacing on steep slopes. They may be reinforced with soil or crop residues to make them more stable (Duveskog, 2001).

Biological methods such as conservation agriculture (CA) (minimum or no tillage), grass strips, strip cropping, crop rotation, agro-forestry, woodlots, use of green manure, crop residues, shrubs (e.g., tithonia), trash lines, and planting vegetation across slopes can improve water infiltration into soil. Conservation agriculture is a tillage system based on (i) minimum soil disturbance (reduced soil tillage), (ii) maintenance of soil cover most of the year, and (iii) crop rotation. This system improves soil cover and reduces soil and water loss. Studies in Uganda show that CA, using permanent planting basins, increased maize grain yield by 30% (Mubiru, 2014).

Grass strips are patches of dense grass planted in strips of about 0.5 to 1.0 m wide, along the contour. The strips create barriers that minimize soil erosion and runoff, through filtering. Silt builds up in front of the strip, and with time, benches are formed. On gentle slopes, the strips are more widely spaced (20-30 m), while on steep land, spacing is 10 to 15 m.

Improve soil water storage

Soil water storage depends on rainfall amount and distribution, soil depth, texture, and structure.

Practices such as runoff water harvesting (Mugerwa, 2007), mulching, minimum tillage, and deep tillage in compacted soils increase water infiltration, reduce evaporation, and store water in soil. Practices that improve soil organic matter, structure, porosity, and aeration and reduce bulk density can reduce soil erosion and increase water infiltration, water storage, and availability to plants.

For sandy soils in hot areas where permeability, evaporation, and organic matter decomposition rates are high, practices that reduce soil disturbance (e.g., mulching, minimum tillage) should be promoted to conserve soil moisture. Soil conditioners (e.g., calcium bentonite, a type of clay) also improve moisture content, resulting in higher crop yields (Semalulu *et al.,* 2014).

Improve soil structure with organic matter

Soil compaction reduces water infiltration and lowers moisture content. In large mechanized farms, continuous use of heavy equipment leads to soil compaction; in grazed areas, overgrazing leads to soil compaction; in smallholder farms, continuous cultivation may compact soil. Practices such as minimum tillage, mulching, use of manure, compost plus alternate growing of shallow-rooted with deep-rooted crops (e.g., pigeon pea) can improve soil organic matter while reducing soil compaction. This in turn improves water infiltration and available soil moisture.

Boost nutrient management

Combined application of organic with inorganic fertilizers improves soil plant nutrient content, and physical and biological properties. In addition, less inorganic fertilizers are applied and, as a result, the risk of nutrient losses to the environment is reduced.

Combined application of organic with inorganic fertilizer increased maize grain yield by nearly 100% and improved fertilizer use efficiency compared to where either of the fertilizers were applied singly (Kaizzi *et al.,* 2002). Similar results were reported with P and farmyard manure on groundnut (Semalulu *et al.* 2014).

No tillage using cover crops can recover the would-be lost N. Cover crops take up N and reduce its loss from the soil. On killing the cover crop, N is recovered and made available to subsequent crops, increasing yield. However, where no-till is used without cover crops but with herbicides used to kill weeds, effects on N uptake and reduced leaching and on yields are less observed.

Recycling plant and animal residues (cow dung, poultry litter, compost manure) and biological nitrogen fixation using legumes can improve nutrient availability. Traditional practices (e.g., natural or improved fallows using legumes, relay cropping) can also improve nutrient availability.

Increase water use efficiency and irrigation

With growing scarcity for agricultural water, there is need to use water more efficiently. Practices that reduce evaporation and improve organic matter management (*e.g.,* mulching, minimum tillage, manure and crop residue recycling, use of cover crops) can enhance infiltration and moisture retention, thereby improve water use efficiency. Choosing crops/varieties that match the agro-ecology (Mubiru, 2010) can also increase water use efficiency. Crops such as sorghum and millet require less water to grow than does maize.

Using proper agronomic practices (cultivating along contour lines, early planting, optimum plant population, intercropping, early weeding) contributes to WaSA. Crop-livestock integration, zero grazing, and optimum stocking rates can also improve water use efficiency.

Water scarcity in smallholder farming can also be addressed through irrigation. In Uganda, the total area under formal irrigation is 14,418 ha out of an estimated 560,000 ha with irrigation potential (Republic of Uganda, 2011). In addition, an estimated 53,000 ha is under informal irrigation for rice in Tororo, Buteleja, Pallisa, Budaka, and Iganga.

Irrigation development will enable farmers to improve their farming practices, mitigate against decreased or intensified precipitation, and reduce the yield gap in traditional producing areas, and thereby address emerging regional market opportunities (Republic of Uganda, 2011).

Respond to water stress

To cope with increasing water shortage in agriculture in the face of rainfall variability, it is important to increase the farming system's buffer capacity by increasing the amount of water stored. Options include roof and runoff water harvesting for domestic and crop/livestock use, enhancing soil water infiltration and storage, on-farm water retention, utilization of groundwater, and supplementary irrigation during critical periods (FAO, 2013).

Cost and benefit of integrated soil and water management

Some ISWM technologies are costly while others are labor-intensive, and their suitability also varies for different areas. Adoption of a particular practice in a given area must therefore be economically justified. On gently sloping land, farmers should use less expensive/less labor-intensive options such as grass strips or trash lines for soil erosion control. Use of locally available materials (crop residues, animal manures, and shrubs such as tithonia) and agro-forestry to improve soil fertility, plus runoff water harvesting could also be considered.

Investment in ISWM technologies should be done preferably on more profitable enterprises and farmers should be linked to markets. Increased access to markets in Uganda resulted in increased adoption and investment in soil management (Delve and Roothaert, 2004).

Facilitating activities that strengthen the entire value chain (e.g., support to water management committees, innovation platforms, value addition and agro-processing, strengthening farmer-market linkages) can serve as incentives to investment in ISWM.

Studies in Uganda show that investment in ISWM technologies is profitable. In Rakai, adoption of contour bunds and mulch improved profitability by more than 200% for banana, coffee, and beans. Farmer adopters were much better off than nonadopters (Kalyebara, 2005). According to Semalulu *et al.* (2014), use of 17 t ha^{-1} coffee husks mulch in pineapple production significantly improved fruit weight and resulted in a fivefold increase in gross margin.

Policy interventions

Many areas require these policy interventions:

(i) Enforcing the adoption of appropriate technologies for controlling soil erosion on various types of land—rangeland, crop land, both gentle and steep slopes.

(ii) More effective by-laws and incentives for enforcing use of improved soil management technologies.

(iii) Improved land tenure systems for management of communal lands, lands belonging to absentee landlords, and wetlands. More effective policies and by-laws to reduce land degradation.

(iv) Introduction of market-led incentives, e.g., market value chain approach to stimulate resource conservation.

(v) Guidelines and bylaws that empower communities to protect and manage their natural resources and the environment.

(vi) Scale up sustainable land use planning on all agricultural land countrywide.

Conclusion

Water scarcity is increasingly affecting Uganda's agriculture. A number of soil and water management technologies exist and have successfully been demonstrated in Uganda. In order to maintain agricultural sustainability, there is a need to scale up these technologies in different agroecological zones, through participatory catchmentwide approaches, supported by a conducive policy environment. For ease of uptake, however, these technologies must be profitable to the farmer.

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