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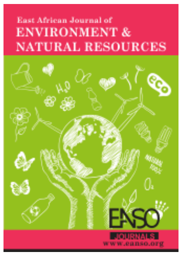

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Original Article

A Review on Challenges and Opportunities in Management of Soils of Arid and Semi-Arid Regions of Kenya

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ABSTRACT

Arid and semi-arid lands occupy currently 88% of arable land mass in Kenya, a region with significant diversity of production systems and economic opportunities. However, these areas are characterised by low and erratic rainfall, hence challenges to agriculture and socioeconomic development in the wake of an increasing population and the impacts of climate change. This review seeks to identify key challenges and opportunities associated with the management of agricultural soils in these arid and semi-arid communities. Arid and semi-arid regions in Kenya are dominated by 10 soil types; Solanchaks, Solonetz, Cambisols, Arenosols, Leptosols, Vertisols, Fluvisols, Phoezems, Calcisols, and Gypsisols. Among the main soil fertility challenges in these soils are moisture stress, high erodibility, and low organic matter content, salinity, and sodium toxicity, the deficiencies of mainly N, P, Zn, and Fe, hence the vulnerability of over 14 million inhabitants to the shocks of low crop and pasture production. Moreover, the adoption of soil conservation practices remains low as existing soil fertility management technologies have been criticized for being too abstract and not providing context and site-specific solutions. Improving soil fertility and moisture levels enhances soil ecosystem functions and food and pasture production in these regions. Encouraging farmers to join soil and water conservation groups, while providing economic incentives, could potentially accelerate the adoption of soil and water practices at the farm level through pulling resources together. Future research to validate a site and context-specific integrated soil fertility improvement technologies for these soils is evitable to enhance soil functions, agricultural production and livelihood at house hold level.

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INTRODUCTION

Arid and semi-arid lands (ASALs) are defined as regions whose ratio of average annual rainfall (r) and average annual potential evaporation (E_o), that is r/E_o is <40%. In Kenya, this accounts for about 88% of Kenya's total arable land. Of the 47 counties, 29 are classified as arid while 14 are said to be semi-arid (Sombroek *et al*., 1982; Njoka *et al*., 2016). Desertification process is spreading fast due to climate change, natural calamities (floods and prolonged drought), and human induced factors that contribute to loss of vegetation cover and top soil rendering more arable land barren. Due to these changes, more semi-humid regions are rapidly transforming into ASALs as more arid land transform into deserts.

Interestingly, ASALs in Kenya render key ecosystem services such as a rich cultural and natural heritage contributing significantly to the gross domestic per capita of the nation. ASALs are home to the plain Nilotes (Njemps, Maasai, Dorobo, Elmolo, Ichamus, Sakweri, Teso, Okiek, Samburu, Turkana, and Marakwet) and cushites (Rendille, Boran, Somali, Oromo, Burji, Boni, Gabbra) (Makolo *et al*., 2005). All lakes, rangelands, and animal conservation/national reserves are located in the ASALs and serve as key tourist destination. Besides, ASALs are endowed with natural resources such as flourspars, limestone, petroleum, soda, and sand among others whose contribution to the economy is paramount. Despite the myriad of challenges bedevilling the ASALs, they support 70% and 90% of the country's total livestock and wildlife population, respectively. This is in addition to supporting a major percentage of the fishing resources and mining industries (Njoka *et al*., 2016; UNDP, 2013).

Despite this natural endowment, ASALs face a myriad of challenges mainly extreme floods, drought, and land degradation, while prolonged drought contributes to death of livestock and loss of vegetation cover, floods, especially on bare lands, cause extreme soil erosion leading to formation of severe gullies. Land degradation has contributed to low crop and pasture production leaving communities dependent on food aid (Waswa *et al*., 2002; Fitzgibbon, 2012). Increasing land degradation is slowly crumbling the fragile livestock-dependent economy in the ASALs leaving the inhabitants extremely vulnerable.

The aim of this review paper is to identify existing challenges and knowledge gaps in the management of soils in ASALs of Kenya. This would inform formulation of policies and design of multi-disciplinary research and developmental projects

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Arid and semi-arid regions of Kenya

Areas considered as arid and semi-arid zones in Kenya are known to cover agro-climatic zones (ACZs) IV to VII, with mean annual rainfall ranges between 150 mm and 550 mm per year for arid zones, and 550 mm and 850 mm per year in semi-arid zones. High temperatures and high rates of evapotranspiration are evident throughout the year. ASALs occupy 88% of the land area in the country and are home to over 30% of the human population and at least 70% of the national livestock herd and over 65% of the wildlife Plate 1. Due to the vast areas prone to drought, Kenya's vulnerability to food insecurity is highest among the pastoralists and small-scale agriculturalists in the ASALs of the country; whereas vegetation in the ASALs ranges across the country depending on altitudes and degree of aridity Plate 1.

ASALs are mostly affected by land degradation, especially where the soils are highly erodible and combined with high intensity storms, creating conditions for excessive runoff and soil erosion. The most affected counties include Samburu, Kitui, Garissa, Tana River, Mandera, Turkana, Marsabit, Baringo, West Pokot, Kajiado, Kilifi, Wajir and Makueni.

Unsustainable agronomic practices and poor-quality irrigation water contribute to increasing land degradation by salinization; a common practice among farming communities in ASALs with about 26,000 ha considered salt degraded (World Bank, 2011). This is caused mainly by poor irrigation management and poor drainage, especially in areas with high ground water table. This therefore requires continuous land degradation assessment and monitoring and indication of the necessary remedial measures before reaching devastating levels.

Climate change in ASAL areas could reduce the growing seasons for pastures and cause drying up of water sources, particularly in the longer term i.e. 20-50 years. Moreover, the numbers of rain days have reduced meaning more intensive storms are experienced, especially in the ASALs, where seasonal rainfall has also declined (Fitzgibbon, 2012).

Increasing human and livestock population have led to competition for grazing lands as extensive grazing remains a major source of livelihoods for pastoralists and agro-pastoralists in Kenya. But most of the rangelands are in the ASALs where pastoralists and agro-pastoralists face competition from increasing influx of farmers from the overcrowded higher potential areas, migrating into the dry lands. This is causing changes in land use, privatization of communal land and increasing pressure on land resources (Fitzgibbon, 2012).

Such pressure on the vegetation in Kenya's rangelands faces an onslaught from both land excision for agriculture as well as increasing livestock densities on the ever dwindling land space left for grazing. This has adversely affected the production potential and carrying capacity of Kenya's rangelands.

Rangeland degradation is evidenced by biodiversity loss and increase in the proportion of bare soil surface and increased erosion has been attributed to livestock overgrazing. This occurs when pastoral communities keep large livestock herds for socio-cultural reasons and as a form of insurance to safeguard households against frequent droughts, crop failure, disease outbreaks and loss of herds to raids.

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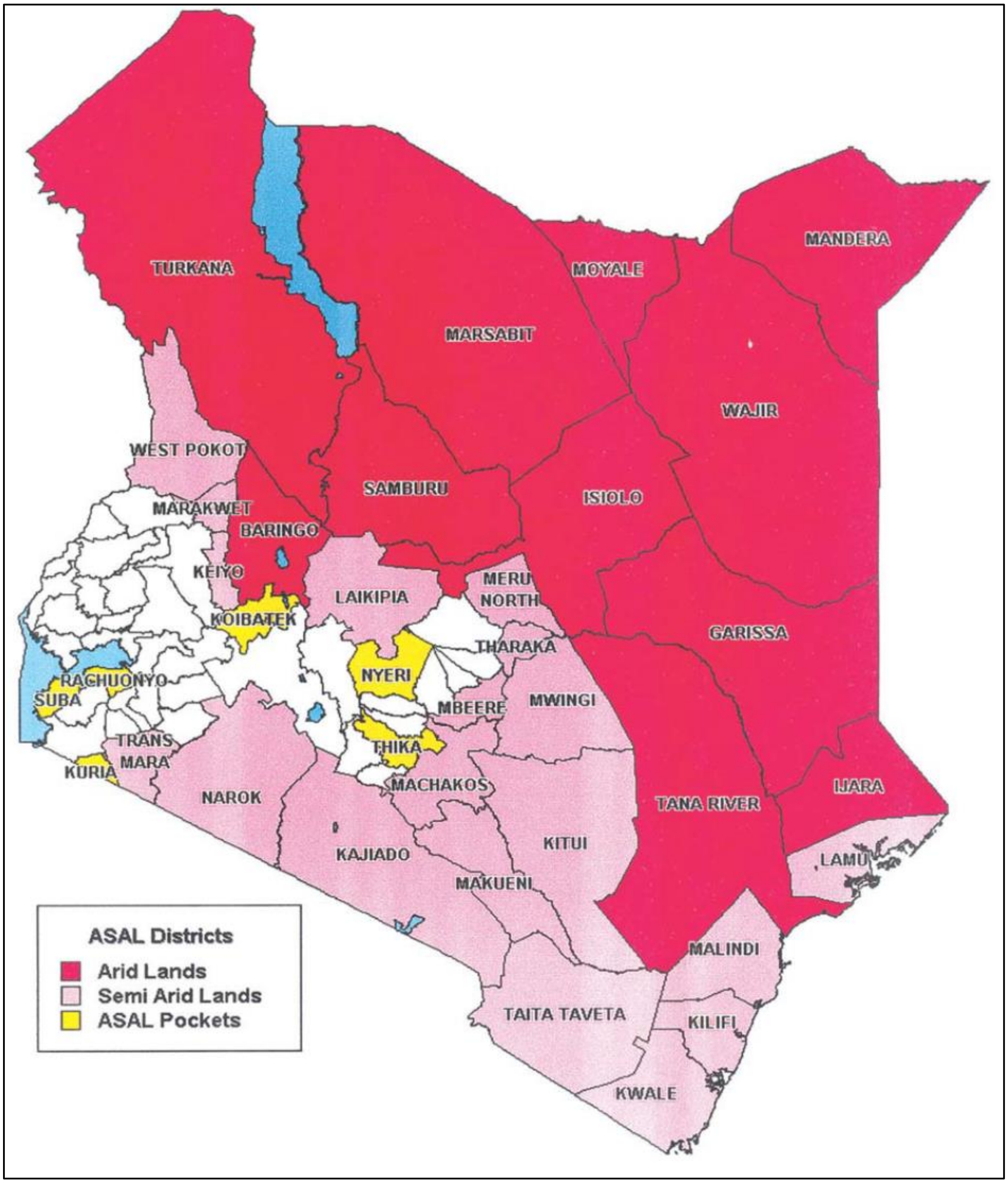
Figure 1: Distribution of ASALS across Kenya. (Adapted from – Arid Lands Resource Management Project



Source: (ALRMP 1993), Office of the President, Nairobi).

ECONOMY OF ASALS

The economic potential of pastoralism in ASALs of Kenya is routinely under-valued (King-Okumu, 2015; Krätli, 2014). This overlooks the much larger proportion of exchange that takes place informally, as well as the value of production that is not marketed. It also takes no account of other direct and indirect benefits of pastoralism such as transport services, informal financial services,

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environmental services, and support to tourism (Krätli, 2014).

Due to the ASALs been occupied by the cushites and plain nilotes, the main economic activity in these regions are livestock dominated by animals such as camels, cattle, goats, sheep, poultry, and bees (both wild and domesticated). With climate change and increasing population, more people are getting into business and other extractive economic activities such as charcoal burning and sand mining and harvesting. ASALs are rich in minerals such as fluorspar, soda ash, gypsum, oil, and limestone. In a few regions such as the environs of Lake Baringo, Lake Bogoria, Lake Elementaita, Lake Naivasha, Lake Turkana, and Lake Nakuru, the dominant economic activities are fishing and tourism.

However, ASALs are best suited for crops such as millet, sorghum, pumpkin, common beans, cow pea, Dolichos lablab, and maize. Additionally, ASALs are best suitable for production of pasture (boma rhode grass, African foxtail grass) fruits (water melons, pumpkins), and vegetables (onions) (Jaetzold & Schmidt, 1982).

It is evident that the economy of the ASALs is mainly dependent on agro-pastoralism characterized by crop, fruit, pasture, and livestock production (Njoka *et al*., 2016). Thus, prudent management of soils of the ASALs is critical to guarantee food and nutritional security to the over 14 million people inhabiting these regions and pasture to the millions of livestock domesticated.

Soils of the ASALs in Kenya

Kenyan ASALs mainly comprise of about 10 soil types whose physio-chemical properties vary widely. These include Solanchaks, Calcisols, Arenosols, Solonetz, Vertisols, Leptosols, Phoezems, Gypsisols, Cambisols, and Fluvisols (Sombroek *et al*., 1982). Their chemical and physical properties are discussed below;

Solonchaks are defined as soils having a salic diagnostic property and lacking natric, gypsic, and calcic diagnostic horizons. These soils have high electrical conductivity >4 dS/cm due to their high concentration of soluble salts. The high salinity induces moisture stress in crops due to increased osmotic pressure around the root zones. The soils are also known for secondary imbalances of nutrients and toxicity. For example, sodium and chlorine could accumulate to toxic levels while Ca could induce P deficiency through sorbing the orthophosphates. Equally, Na could impair uptake of calcium and magnesium while chlorine could impair metabolism of nitrogen (IUSS Working Group WRB, 2015)

Calcisols – Calcisols are defined as soils having a calcic diagnostic (characterized by high accumulation of calcium carbonates in either the surface or subsurface horizons) and lacking a salic, gypsic and natric diagnostic horizons. These soils are known to exhibit pronounced deficiency of zinc and iron. In addition, they have high salinity levels that induces water stress to crops (IUSS Working Group WRB, 2015).

Arenosols – Arenosols are defined as soils having an arenic diagnostic horizon. This is a horizon characterized by high sand levels, usually >70%. This makes the soils to have a low cation exchange capacity and highly erodible due to their low levels of clay particles (IUSS Working Group WRB, 2015). Arenosols are a significant source of sand used in the construction industry. Sand harvesting from areas having Arenosols have been a significant course of community conflicts, spurred gully erosion, and clearance of vegetation leading to increasing desertification (UNDP, 2013; IUSS Working Group WRB, 2015).

Vertisols are soils defined by their presence of a vertic diagnostic horizon. They have clay content >40% making them poorly drained and high moisture stress during the dry seasons. When dry, Vertisols have wide cracks which hinder crop production. However, generally they are fertile soils owing to their high cation exchange capacity and their main limitation is moisture (IUSS Working Group WRB, 2015).

Fluvisols are soils developing along riverine due to deposition of colluvium and alluvium materials. These soils are very fertile and mainly used for intensive crop farming in the ASALs to grow crops such as vegetables, cereals, fruits, onions, tomatoes, bananas among other crops (IUSS Working Group WRB, 2015).

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Solonetz are defined by presence of a natric diagnostic horizon. This is characterized by high accumulation of sodium carbonate or exchangeable sodium >15%. In addition, they are poorly drained due to high accumulation of clays in the B horizons and high probability of hard setting and crusting. Na toxicity is a major limitation to crop production in these soils and hence are not used for food crop but only fodder production (IUSS Working Group WRB, 2015).

Leptosols are soils defined by their shallow depth of <50 cm overlying a continuous rock. These soils are rich in primary nutrients since weathering is still taking place. Due to their occurrence in semi-arid and arid areas where temperatures are high, they have high economic value supporting fruit production in the ASALs under irrigation. However, they are highly prone to erosion (IUSS Working Group WRB, 2015).

Cambisols are characterized by their cambic diagnostic horizons and high amounts of primary minerals due to their slight or moderately weathered profile and absence of appreciable quantities of illuviated clay, organic matter, and sesquioxides. They are mostly found in the mountainous regions (IUSS Working Group WRB, 2015).

With increasing desertification, more soils previously under the semi-humid regions are likely to now occur under the ASALs region. Some of these include Acrisols, Planosols, Phaeozems and Lixisols (IUSS Working Group WRB, 2015). Finally, a few regions in the ASALs, especially those under swamps have Gleysols.

Challenges facing Soils of the ASALs

ASALs are faced by three major challenges that engulf the residents to a vicious poverty cycle. These are frequent droughts, water scarcity, and soil degradation. These have increased the vulnerability of the residents and their livelihoods (UNDP, 2013). In severe situations, food insecurity and malnutrition may lead to death of people and livestock. Soil degradation, mainly through soil erosion, is intense that in most regions it has developed into very severe gullies that have hampered movement of people and goods besides reducing significantly the available arable land (Jungerius *et al*., 2002; Sigunga *et al*., 2011; Konana, 2017; Peterson *et al*., 2018).

Gully Erosion

Gullies are defined as geomorphic features larger than 0.5 m and hence difficult to rehabilitate using tillage implements (Valentin *et al*., 2005). Severe erosion was first registered as an environmental concern in early 1930s in Kenya. Unfortunately, this has continued unabated, leading to formation of large gullies spread across many ASALs counties (Ongwenyi *et al*., 1993). These are Samburu, Laikipia, Tana River, Kajiado, Narok, Kilifi, Mandera, Kitui, Makueni, Garissa, Baringo, Wajir, and West Pokot (Sigunga *et al*., 2011; UNDP, 2013; Konana, 2017; Peterson *et al*., 2018; Watene *et al*., 2021). Despite erosion affecting both low (arid to semi-arid) and high potential (humid to sub humid) counties, it is more pronounced in the former (ASALs) (Kiome & Stocking, 1995; Ovuka, 2000, Mulinge *et al*., 2016; Watene *et al*., 2021). ASALs are said to be more susceptible to water erosion leading to loss of vegetation cover, hence contributing to increased desertification in Kenya (Watene *et al*., 2021).

Gully morphology in Kenya varies widely. However, based on shape of the channel. They can be classified into three shapes; entrenched U, trapezoidal, and dendritic V-shaped gullies (Rowntree, 1991). On the other hand, gullies can be classified into continuous channels, which could take any shape described above, or braided shallow channels with earth pillars (Sigunga *et al*., 2011) as shown in Plate 2. The entrenched dendritic V shaped gullies are prevalent in soils with low infiltration due to sodium rich or a shallow regolith overlying bedrock shaped gully (Rowntree, 1991). The continuous channels occur in soils having high exchangeable sodium, low infiltration especially the lower horizons and highly dispersible. The braided ones occur in soils with high exchangeable sodium in addition to being coarse-textured and an impermeable top layer of hard crust (Sigunga *et al*., 2011).

Plate 1: Two types of gullies based on continuity channel, a) braided channels with earth pillars and b) continuous channels with parallel banks

Source: (Photos courtesy of second author)

Evaluation of soil loss due to gully erosion has not been possible at large scale due to limitations of existing models such as Revised Universal Soil Loss Equation (RUSLE) which have been developed for estimating soil loss due to rill, interill, and sheet erosion (Kogo *et al*., 2020). Studying gully erosion is very complex due to interactions of many drivers as opposed to sheet or rill erosion which is easy to predict. In most cases, researchers opt for field measurements method which is expensive and labour intensive (Gitonga, 1994). Gully erosion could be contributing to massive soil loss compared to sheet and rill erosion which has been predicted to contribute to soil loss at the rate of 1 - 40 t ha^{-1} yr^{-1} in Kenya, depending on soil type, slope, and vegetation cover (Kogo *et al*., 2020; Watene *et al*., 2021).

Drivers of Gully Erosion

Gully erosion is accelerated by a multi-interaction of various factors such as unfavourable and ineffective policies regarding land ownership, sand mining, changes in land use and cover, road construction without appropriate drainage channels, inappropriate discharge of water from roads or buildings such as markets and schools, urban centres, deforestation and through indiscriminate tree logging or bush burning, vegetation loss through prolonged droughts or over-grazing, steep slopes, over-stocking, foot and livestock paths, heavy rainfall intensities and intensive farming (Rowntree, 1991; Gitonga, 1994; Ovuka, 2000; Jungerius *et al*., 2002; Waswa *et al*., 2002; Konana *et al*., 2017; Asuoha *et al*., 2019; Hassen & Bantider, 2020; Watene *et al*., 2021). In communally owned land especially group ranches, agro-pastoralist farmers are not motivated to engage in the expensive and time-consuming rehabilitation activities (Njoka *et al*., 2016). On the other hand, sand mining along river-beds, contribute to widening and deepening of river banks and beds, thus disrupting transport networks while threatening productivity of adjacent farms.

Besides the above drivers, soil physio-chemical properties could accelerate formation of gullies. These include soil with high content of water dispersible clays, low organic matter, low bulk density, high silt and sand content, high exchangeable sodium percentage, and expanding clays (Rowntree, 1991; Gitonga, 1994; Waswa *et al*., 2002; Valentin *et al*., 2005; Igwe & Udegbunam, 2008; Sigunga *et al*., 2011). It has been shown that soils with high sand content are prone to crusting, reducing infiltration rates and hence generating massive surface runoff that contribute to formation of ephemeral gullies (Poesen *et al*., 2003). Despite lack of strong correlation between soil types with gully formation (Waswa, 2000), some soil types due to their inherent physical and chemical characteristics are more vulnerable to gully erosion. Arenosols, Andosols, Leptosols, and Solonetz are more vulnerable to gully formation due to weak physio-chemical properties (Gitonga, 1994; Valentin *et al*., 2005; IUSS Working Group WRB,

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2014; Watene *et al*., 2021). Andosols have low bulk density and high silt and sand content. Solonetz contain high levels of sodium which is responsible for clay dispersion/deflocculating while Leptosols are young soils with high contents of silt and sand.

These drivers work inter-dependently and concurrently. However, the factors differ considerably from place to place. Understanding the drivers of gully erosion in an ecosystem is critical in development of rehabilitation and soil conservation plans (Hassen & Bantider, 2020).

Impact of Gully Erosion

Gully erosion had had very devastating effects on people and environment which include, but not limited to loss of life, displacement and separation of people, loss of vegetation cover, destruction of roads, loss of livestock, reduction in arable land, reduction in crop and fodder yields, siltation of water reservoirs, loss of top soil, and plant nutrients (Igbokwe *et al*., 2008; Konana, 2017; Hassen & Bantider, 2020). In some cases, very severe gully erosion could expose the water table leading to formation of new streams, and hence more water availability.

Several studies have evaluated the impact of severe erosion on people and their livelihoods as well as the environment in several counties; Kajiado, Kisumu among others. However, little has been documented on how the process affect community attributes of soil macrofauna. Severe erosion could affect the soil fauna through several mechanisms which include total displacement, loss of food resources and destruction of their habitat. Unfortunately, there are limited studies focusing at how population and diversity change after severe erosion has occurred.

Soil Fertility Management and Soil Conservation

It has been shown that households which have adopted integrated soil fertility and water conservation practices are more likely to be food secure during occurrence of prolonged droughts than those without (Mutuku *et al*., 2017).

Soil Fertility Management in the ASALS

Soil fertility in Kenyan ASALs is mainly dictated by limited soil moisture and deficiency of N and P (Gachimbi *et al*., 2002; Okalebo *et al*., 2007). Soils in the ASALs have low water holding capacity. In addition, high salinity induces water stress by increasing osmotic pressure around the root zones. Deficiency of N is aggravated by losses such as volatilization, leaching, and surface run-off while P is sorped by Ca while a significant part of it is lost through surface run-off. Thus, management practices must focus on an integrated approach aimed at improving soil N and P contents, soil moisture, and cation exchange capacity. For this reason, farmers must apply organic and inorganic fertilizers to achieve optimal yields (Okalebo *et al*., 2007) in addition to soil moisture conservation measures such as tied ridges (Mutuku *et al*., 2017).

However, there is need for further validation of the recommended rates of manure application in the ASALs. Although farm yard manure has been shown to reduce soil compaction (Biamah *et al*., 2007), the available rates are too high for most of small-holder farmers. In Eastern Kenya, 10 t/ha of farm yard manure (FYM) alongside 20 kg of P_2O_5 ha^{-1} has been recommended (Gichangi *et al*., 2007). These are quite high and validation of micro-dosing/banding or whole application of manure could be pursued to provide a more sustainable solution for the farmers in the ASALs.

In addition to N and P deficiency reported by Okalebo *et al*. (200), deficiency of Fe and Zn is likely to be dominant. This is mainly attributed to the high soil pH common in the ASALs of Kenya (Sombroek *et al*., 1982; Marschner, 2012). However, there is no existing scientific evident to support or disapprove this argument in Kenya.

P sorption has been researched extensively in Kenya targeting the acidic soils. Major solutions evaluated so far include; liming, use of low solubilizing fertilizers such as Mijungu rock phosphate (MRP) and organic fertilizers. About 2 t/ha or agricultural lime have been recommended to mitigate P sorption (Nyambati, 2000; Kifuko *et al*., 2007; Kisinyo *et al*., 2013; Muindi *et al*., 2014; Kisinyo *et al*., 2014). However, little has been done for the ASALs. In addition, despite Zn and Fe deficiency being a

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common occurrence in the ASALs, there is little evidence to support this argument in Kenya. However, in some parts of Western Kenya, Zn deficiency has been shown to reduce maize production.

Integrated combination of organic and inorganic fertilizers combined with soil moisture conservation measures such as tied ridges have been recommended for the hot semi-arid regions of Machakos, Kitui, Mwingi, and Mbeere. Application of 10 t/ha of FYM and 20 kg/ha of both N and P_2O_5 was found to significantly increase maize yield while optimizing profits (Gichangi *et al*., 2007).

Soil Conservation in the ASALs

Soil Conservation Measures

Rehabilitation of gullies is labour and capital intensive (Hassen & Bantider, 2020) and several measures have been recommended for gully rehabilitation and prevention. These include terraces, check dams, zero or reduced tillage, controlled grazing, stone bunds, seeding of bare rangelands, afforestation, cover cropping, incorporation of organic matter trash lines, stone bunds, grass lines, and ridging (Kiome & Stocking, 1995; Waswa *et al*., 2005). Among the gully rehabilitation measures include check dams, enclosures, cut off drains, seeding vegetation, gabions, afforestation, grassed water ways, and shrubs or grass hedges (Gitonga, 1994; Poesen *et al*., 2003; Eriksson & Kidanu, 2010; Mati, 2012; Wairore *et al*., 2015). In areas where gullies have already formed, it is critical to combine both preventive and rehabilitative measures. Sand dams, a popularly known water harvesting technology, has proven effective in controlling gully erosion as well as river bank erosion.

Sand dams

Traditionally, sand dams have been used to harvest and conserve water for domestic and agricultural purposes in the arid and semi-arid lands of Kenya (Maddrell, 2018; Neufeld *et al.*, 2021). Through improving water availability in the sand aquifers and their surroundings, sand dams have proven a suitable tool for enhancing adaptations of ASALs to climate change through vegetation regeneration (Lasage *et al*., 2008) and conserving and increasing availability of domestic water during the dry seasons for durations up to four months (Ryan & Elsner, 2016). This reduces the distance from which the community would travel in search of water, cushioning farmers against effect of drought. Farmers in the ASALs use shallow wells and scooping holes to abstract water from sand dams (Quinn *et al*., 2018). Shallow wells have been reported to be a safer water abstraction method from sand dams against scooping holes which is prone to pollution (Quinn *et al*., 2018; Moise et al., 2019; Grabar *et al.*, 2020).

Despite being accepted as a water harvesting technique globally, the potential of sand dams to conserve soils and their contribution to controlling gulley erosion has not received much recognition. The potential of utilizing sand dams for soil and water conservation is evident based on its operating principle. Soil materials are intercepted by sand dam wall filling the volume upslope. However, it is believed that sand dam intercept only sand particles, a myth that is not true. Existing literature although scanty, provide contradicting data on the composition of sand dam materials. While majority report sand and water as the only materials collecting behind the sand dam wall (Maddrell & Neal, 2012), silt and clay have been reported in a recent study by Neufeld *et al*. (2021). Indeed, silt, clay, and organic matter could collect as the sand dam given that materials intercepted are always a reflection of the soils upslope. Ideally, there is no soil including Arenosols that is 100% sand (IUSS Working Group WRB, 2015) or soils existing in areas with zero vegetation cover to exclude any chances of organic matter collecting. Elucidating the composition of materials intercepted by the sand dams, is key in helping understand their contribution to restoration of the ecosystem and how such materials affect the quality of water.

Vegetation cover

Vegetation cover provides protection against rain drop effect by intercepting energy of the raindrop, increasing the infiltration rates thus reducing surface run off, and holding soil particles, reducing their dispersion by water (Reubens *et al*., 2016). These can either be food crops, fodder, trees, or shrubs. They can be planted inform of cover crops,

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farm enclosures, or woodlots. Crops and fodder crops such as sweet potato, pumpkin, grass, dolichos lablab trees, among others have been documented as effective cover crops. Such cover crops, especially the grass, could be seeded in bare rangelands or in active gullies. Trees and shrubs (mostly finger euphorbia and sisal) are very effective used as farm enclosures. Finger euphorbia have been recommended for seeding around gully heads to reduce receding (Gitonga, 1994). Due to the multiple needs of the agro-pastoralist farmers, in terms of food and nutrition, fodder, soil conservation, incomes, and soil fertility improvement, there is need to promote participatory selection of cover crops, shrubs, or trees that have multiple uses.

Terraces

Terraces were introduced into Kenya in 1930s by the colonial government. African farmers participated in terrace construction through forced labour and punishment were instituted on those who defied. Here, several types of terraces were adopted by farmers in Kenya since the colonial time. These include *fanya juu* (also known as bench terraces) and *fanya chini* (also known as water retention ditches) (Ovuka, 2000). To stabilize the terrace nests, napier grass, grass strips, and sisal were planted on the ridges (Ovuka, 2000). Terraces contribute significantly to reduction in soil erosion, siltation of water reservoirs, and flooding while increasing water harvesting (Kiome & Stocking, 1995; Mupenzi et al., 2012; Saiz *et al*., 2016). Although terraces have been reported to increase crop yields, contradictory results on its economic viability as well as its contribution to enhance soil fertility has been reported (Posthumus & Stroosnijder, 2009; Kagabo *et al*., 2012; Rashid *et al*., 2016). However, when combined with other measures such as soil cover, terraces have been reported to increase soil carbon (Saiz *et al*., 2016; Chen *et al*., 2020).

Adoption of terrace technology in soil conservation is hampered by its high labour intensity, high cost of management, limitation in farm mechanization after installation, and finally, the negative attitude created during colonial time through forced labour on African farmers (Ovuka, 2000). Terraces are high-cost investment limiting its adoption among small scale farmers. This disincentive could only be resolved when the installation is done under community-merry-go round models (Kiome & Stocking, 1995). Terrace erosion is one of the threats to its adoption and management. This was reported in Kenya in early 1960s in Narok regions and was attributed to trampling and overgrazing and differential in soil compaction across the soil layers (Glover & Wateridge, 1968).

Soil Moisture Conservation Measure

Soil moisture conservation in the ASALs is very key in optimizing nutrients uptake and hence crop yields. Management of soil moisture in the ASALs also aims at managing the salinity levels to avoid induced moisture stress, nutrients imbalance, or toxicity. Several methods have been evaluated for managing soil moisture in the ASALs. These include tied ridges, timely planting, zero-tillage, addition of organic matter such as chicken and FYM, terraces, *zai* pits, mulching, and cover cropping (Mutunga, 2001; Muriuki & Macharia, 2011). However, for these to function efficiently, farmers in the ASALs must embark on massive tree planting to modify the micro-climate in these regions and significantly reduce the evapotranspiration. The only solution to water scarcity in the ASALs is however, irrigation and intense tree planting. Irrigated agriculture for the high value crops has great potential as game changer of the agro-economic base of the ASALs. However, this must be integrated with intense tree planting to reduce the evapotranspiration rate. For adoption of these interventions, the communities must be trained to change their perception and attitudes (Mugera, 2015).

Community Participation in Gully Rehabilitation and Soil Conservation

The first effort of soil conservation in Kenya dates back in 1930. This was implemented through forced labour by the colonial government on fields owned by African farmers. This was done through terracing, strip cropping, destocking, contour farming and tree planting. Unfortunately, due to the unsustainable model used of forced labour, the conservation temporary stopped in 1962 just before Kenya attained independence (Republic of Kenya, 2020). Soil conservation was later reintroduced in

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Kenya in 1974 with formation of Kenya National Soil Conservation Project (KNSCP). This came through after soil degradation was regarded as the main environmental threat during the United Nations Conference on Human and Environment in 1972. Farmers were given tools for soil conservation. Later the KNSCP was replaced by Catchment Approach (CA) in 1988 which required soil conservation officers and farmers to collaborate in establishing soil conservation in specific catchment areas. This project ended in 1998 (Ovuka, 2000). Later in 2000 to 2010, Kenya launched another project (National Agriculture and Livestock Extension Programme (NALEP) which however had no much emphasis on soil management but generally on all aspects of farm management (Republic of Kenya, 2020).

Farmers in most cases understand environmental changes taking place at farm. For example, farmers are aware of land degradation processes such as gully erosion and have local adaptations which include use of cheaper soil conservation measures such as trash lines, stone gabions, and stone bunds (Kiome & Stocking, 1995). Under severe erosion, farmers abandon the severely degraded land leaving them more vulnerable to drought effects, further land degradation as well as food and nutritional insecurity. Thus, there is need for concerted efforts to assist farmers rehabilitate degraded lands while controlling further soil erosion.

The success of sustainable rehabilitation of gully erosion and soil conservation is anchored on community engagement, adopting bottom-up approaches, promoting economic incentives, implementing a holistic management plan of the watersheds, and integration of local technologies in SWC. Unfortunately, many projects engaged in soil conservation only focus on sustainability of their interventions in the last project phase threatening the gains achieved (Nigussie *et al*., 2018). In addition, most technologies are developed by researchers under the "linear model of research and development" where farmers and extension agents are perceived as recipients of the outputs and not partners. This model limits farmers' involvement and hence leading to low adoption of technologies (Sherwood & Uphoff, 2000).

In Ethiopia, economic incentives promoting farmers to invest in soil and water conservation have been recommended to replace compulsory labour and food for work incentives, which have been cited as inappropriate and unsustainable (Nigussie *et al*., 2018). Community based organizations are the heart of successful rehabilitation efforts and thus strengthening their information, financial, and leadership capacity is integral in entrenching sustainability of soil and water conservation (Waswa *et al*., 2002; Nigussie *et al*., 2018). Building and strengthening the capacity of community to timely detect early indicators of land degradation compliments their efforts in soil conservation and rehabilitation.

CONCLUSIONS

ASALs occupy currently 88% of the arable total land mass in Kenya. They are dominated by ten soil types; Solanchaks, Solonetz, Phoezems, Cambisols, Arenosols, Leptosols, Vertisols, Fluvisols, Calcisols and Gypsisols. Among the main soil fertility challenges in these soils are salinity, sodium toxicity, deficiency of mainly N and P, soil moisture deficit stress and high erodibility, which expose the over 14 million people residing here to food insecurity and malnutrition. Improving soil fertility while managing soil erosion is inevitable to achieve sustainable food and pasture production. However, adoption of soil conservation still remains low. Encouraging farmers to join SWC groups could potentially accelerate adoption of SWC at the farm level through pulling resources together. Communities must be sensitized to climate-smart agricultural strategies such as agroforestry, especially fruit and fodder trees to achieve food and nutrition security, protect the soil against erosion and provide suitable micro-climate for crop production. Finally, there exist several gaps in current soil fertility improvement technologies which require further to; validate site and context specific integrated soil fertility improvement technologies for the ASALs farmers, development of more innovative irrigation technologies which take into account low water availability and high evapotranspiration rates experienced in these regions, develop mitigations for P sorption and finally elucidate the contribution of micronutrients deficiency and their contribution to low production.

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