Chapter 22
The Role of Forages in Sustainable Intensification of Crop-Livestock Agro-ecosystems in the Face of Climate Change: The Case for Landscapes in Babati, Northern Tanzania

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Abstract Agro-ecosystem productivity is highly dependent on soil moisture fluxes yet climate change induces unpredictable dynamic interactions on water and nutrient resources. This study assessed on-farm seasonal productivity, runoff and soil moisture storage estimates within forage grass and forage legume intercrops at the Long site in Babati District of Northern Tanzania and how these would be impacted by climate change. The WaterWorld model was used to ascertain the impact of climate change on temperature and moisture fluxes at landscape level within these agro-ecosystems. Study results revealed a steady increase in temperature and a projected increase in rainfall over the next 40 years to the 2050s with an average future precipitation of 1300 mm yr^{-1} compared to the current baseline of 960 mm yr^{-1}. On-farm seasonal water balance estimates within forage grass–forage legume intercrops revealed that with the 645 mm of rainfall received in the 2014 rainy season, evapotranspiration (ET) was the predominant factor accounting for about 75 % of the fluxes. We demonstrate that compared to the control trials, runoff

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levels were significantly lower in areas with forage grass–legume intercrops which translated to 20 % lower runoff levels; there was higher soil moisture storage with an average of about 25 mm (30 % higher) in areas with forage grass–forage legume intercrops than the bare plot control areas. The Napier-Desmodium and Napier-Lablab combinations had about 15 % higher soil moisture storage and 30 % higher water productivity compared to the sole Napier accessions. The sole forage grasses depicted about 15–50 % higher runoff levels compared to the Napier-Desmodium and Napier-Lablab combinations. In doing so, a combination of perennial forages (grasses and legumes) improves the sustainability of farming systems through erosion control and soil moisture retention beyond serving as feed resources. Using both qualitative and quantitative metrics from this study, we draw on the sustainable intensification indicators framework to illustrate explicit linkages on synergies and tradeoffs associated with forage interventions within smallholder farming systems. Sustainable intensification within these landscapes will thus require more innovative solutions that incorporate establishing different types of alternative forage grass–forage legume combinations coupled with other improved agronomic practices into a compendium package of interventions that allows for sustainable land use to cope with climate change and variability.

Keywords Sustainable intensification · Climate change · Adaptation · Farmer options · Innovative solutions

22.1 Introduction

Historically, agroecosystems the world over have responded rather resiliently to the increasing pressure for producing food for an expanding human population (Robertson et al. 2014). As a result, it is not surprising that recent years have witnessed a gradual but steady increase in urbanization and prominent rise in incomes of emerging economies (Cohen 2006), with shifting of human diets toward higher consumption of calories, fats, and animal products (Nair 2014). This therefore calls for exploring novel and sustainable ways of intensifying agro-ecosystems to ensure higher crop and forage productivity that reduces competition between man and livestock for food and feed respectively. This is more pertinent than ever because climate change is among the plethora of factors affecting crop and livestock productivity resulting in negative impacts on livelihoods in semiarid landscapes as evidenced in portions of central and northern Tanzania.

Climate change is further expected to exert more pressure on water and agriculture with potential negative impacts on livelihoods. The vulnerability of Northern Tanzania is high due to the large number of households that depend on the natural resource base for their livelihood. Consequently, there is a growing need for ‘anticipatory adaptation’, in a more proactive rather than reactive management of climate change risk. The productivity of agro-ecosystems in the region is controlled primarily by water dynamics an aspect that is intrinsically linked with the amount and distribution of rainfall. This also affects agricultural productivity among smallholder farmers in SSA, namely crop enterprises, cropping calendars, incidence and growth of weeds, crop pests and diseases. This erratic variability of climate exacerbates environmental vulnerabilities which in turn affect the poorest segments of society. Recent studies indicate that 40 and 26 % of agro-pastoralists in Kiteto and Longido districts respectively identified climate variability and extreme climate events, especially, as the major challenge to sustained livestock and agricultural productivity. In particular, frequent and prolonged drought and insufficient pasture of good quality and quantity were noted as results of climate variability (Coulibaly et al. 2015) that impact sustainable intensification of crop-livestock mix agro-ecosystems. As a result of these climate induced seasonal changes, livestock death and crop failure are frequent in the two districts.

Sustainable intensification innovations, such as integrated land and water management practices and agroforestry practices, can provide win–win solutions through improving yields and land and animal productivity; hence food security. Other associated benefits include improved ecosystem services and socioeconomic benefits, and increased resilience to climate change and associated extreme weather events, such as water scarcity, intense rainfall, or droughts. These benefits occur as a result of increase in soil organic matter, improved soil structure, reduced soil erosion, increased water filtration and efficiency of water use, replenishing of soil nutrients, and increased efficiency of nutrient uptake (Winterbottom et al. 2013). For instance, in situ rainwater harvesting complemented with agroforestry and/or nutrient management practices such as micro dosing has been known to double or triple crops yields in the Sahel (Winterbottom et al. 2013), a region with similar climatic conditions to semiarid central Tanzania. These practices are currently being promoted and scaled up within Africa RISING sites in Babati, Kongwa and Kiteto to sustainably intensify farming systems to increase yields, reduce land degradation and increase community resilience through diversified production and income options (Okori 2014).

This study (1) Assessed forage water productivity within forage grasses–forage legume intercrops compared to sole forage grass monocrops and bare control plots; (2) Determined on-farm erosion, runoff and soil moisture storage dynamics within forage grasses–forage legume intercrops compared to sole forage grass monocrop; and bare control plots; (3) Projected regional climatic trends that impact on both farm-scale and catchment-scale water management in Northern Tanzania over the next 40 years to the 2050s; (4) Assessed study results against the sustainable intensification indicators framework to discern synergies, tradeoffs and minimize unintended negative consequences in future work. We posit that where applicable, incorporation of forage grass and forage legume combinations into smallholder farming systems (from farm-scale to landscape level) will play a critical role towards higher crop and forage water productivity, increased soil retention and nutrient composition and improved agricultural soil moisture management.

22.2 Materials and Methods

22.2.1 Site Characteristics

The study was conducted in the Babati district of Northern Tanzania (Fig. 22.1), located between the latitudes 3° and 4° south and the longitudes 35° and 36° with an altitude between 1650 and 2250 m above sea level. The Region is a part of the Great Rift Valley and the landscape is characterized by mountains, undulating hills and plains. The precipitation varies with the altitude and ranges from 1200 mm/year in the highlands down to 500 mm/year in the lowlands. The rains are predominantly unimodal with the major rains of the growing season between February and May (Bishop-Sambrook 2004). Based on description given by Kihara et al. (2014), the area is characterized by low fertilizer use and has one lengthy growing season between November and June. Maize is mainly grown as an intercrop with a late maturing pigeon pea (*Cajanus cajan* L. Millsp.) cultivar. The soils are mainly of volcanic origin and range from sandy loams to clay alluvial soils. The content of organic material and availability of phosphorus is generally low across the district (Jonsson 1996). Many farmers in Babati District are agro-pastoralists and the number of livestock in the area is high, livestock rearing constitutes about 35 % of the overall land use in the district (Shetto and Owenya 2007). In some areas, farmers practice traditional post-harvest grazing which is not compatible with systems where soil cover is desired or where contour bunds are practiced.

22.2.2 Experimental Setup

A total of three Napier grass accessions (KK1, KK2, and ILRI 16837) were grown and harvested every 6 weeks at an on-farm trial replicated three times (Fig. 22.2). The replications were a combination of Napier grass (*Pennisetum purpureum*) accessions with Desmodium (*Desmodium uncinatum*), Lablab (*Lablab purpureus*) and the sole Napier grass of each accession (KK1, KK2, and ILRI 16837). The choice of these forage combinations were a result of prior participatory variety assessments involving 77 farmers on the field trials using a rating and voting exercise where farmers identified and ranked their preferred characteristics. The main characteristics identified by farmers included the number of leaves and shoots, tolerance to drought, rapid regeneration and length of stem after harvest. In addition, control plots that had neither sole forage grass nor forage grass–forage legume combinations were used to discern soil moisture flux differences.

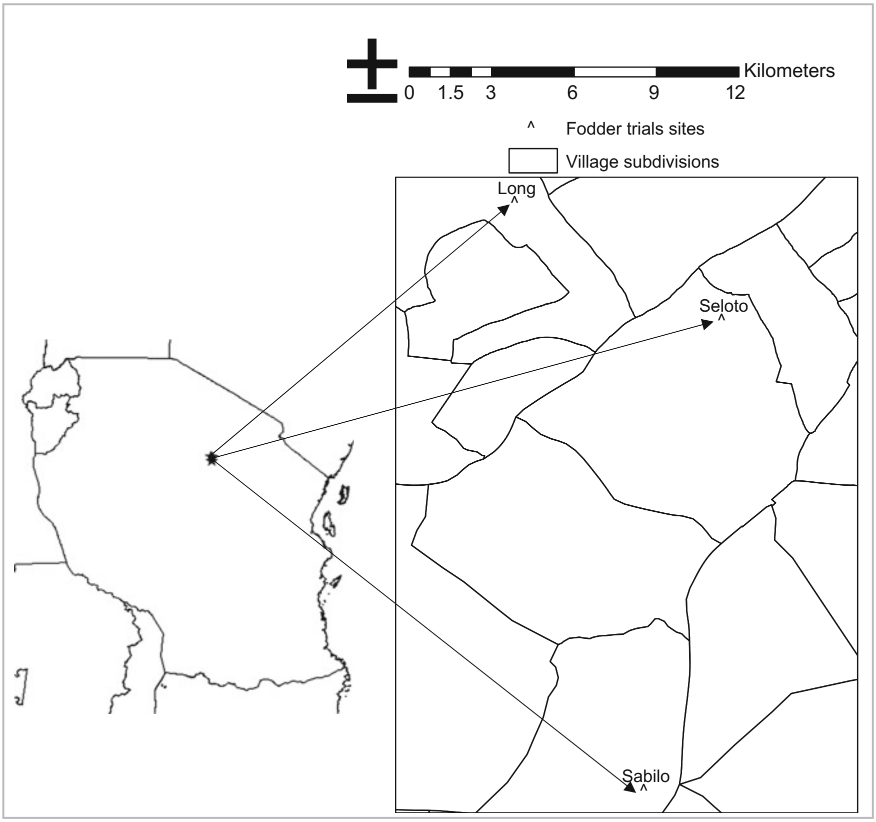

Fig. 22.1 Location of forage grass–forage legume trials in the villages of Long, Seloto and Sabillo in Babati district, Manyara region of Tanzania (*Note* that this paper only reports results from Long site)

22.2.3 Micro-Climatic Data Collection for Forage Water Productivity Estimates

All micro-climatic parameters were measured using an automated weather station (Spectrum 9 Technologies) at hourly intervals. Rainfall was monitored with a tipping bucket rain gauge (0.5 mm per tip) and evapotranspiration was estimated using the modified FAO Penman–Monteith approach at hourly intervals. Daily reference crop evapotranspiration (ETo) was computed from measured meteorological data; namely solar radiation, air temperature, relative humidity and wind speed. The FAO Penman–Monteith equation (Allen et al. 1998) used for hourly time steps (for a well-watered crop) in this study Eq. (1) is:

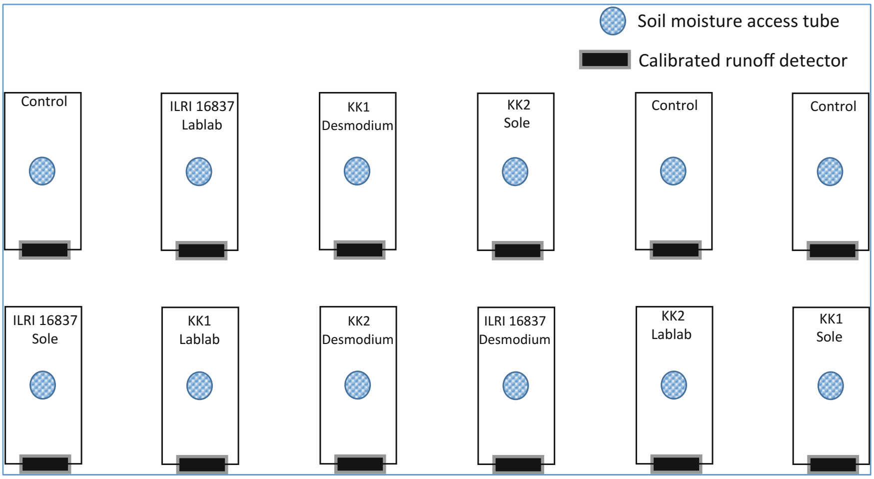

Fig. 22.2 Experimental set up of forage-grass and forage-legume interactions showing soil moisture access tubes and runoff soil trap detectors with each plot measuring 10 m × 5 m

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{37}{T_{hr}+273}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (22.1)$$

where ETo is the reference crop evapotranspiration (mm h^{-1}), Rn the net radiation (MJ m^{-2} h^{-1}), G the soil heat flux density (MJ m^{-2} h^{-1}), T_{hr} is the mean hourly air temperature (°C), (e_s–e_a) the hourly vapor pressure deficit of the air (kPa), Δ the slope of the saturation vapour pressure function (kPa °C^{-1}), γ the apparent psychrometric constant (kPa °C^{-1}), u_2 is the average hourly wind speed (m s^{-1}) measured at 2 m above the soil surface.

Forage water productivity is the amount of water required (crop evapotranspiration, ETc) per unit of biomass yield (Amede et al. 2009) and is a vital parameter to assess the performance of agricultural systems for targeted integrated water resources management.

$$Forage\ Water\ productivity = \left(\frac{Forage\ yield(Y)}{Forage\ Evapotranspiration\ (ET_c)}\right) \quad (22.2)$$

Forage water productivity will vary greatly according to the specific conditions under which the crop is grown. There are standard procedures used to assess forage water productivity in the context of the framework of water management applications and practices (FAO 2006). A suite of these procedures was used in combination with the seasonal forage yield averages from primary field data to estimate forage water productivity at the study site.

22.2.4 On-Farm Runoff and Soil Moisture Storage Dynamics Within Forage Trials

Within the Napier grass accessions, soil moisture measurements were conducted using a Diviner 2000 Probe Series. Measurements were conducted every week over a 2-year period (2014–2015) within the forage trials. The Diviner 2000 probe soil moisture data was calibrated gravimetrically under field conditions. For the vertical profile study, measurements were conducted at 0.10 m depth increments to a depth of 1.0 m. Profile stored water was calculated on a depth basis as the product of volumetric water-content and the depth interval (0.10 m) and expressed as millimeters of water. In this study, we present a mean value of soil moisture storage for the 0–40 cm depth range. Erosion assessments were conducted with flexible corrugated iron cubic boxes of 15 cm dimension providing a total cubic volume of 3375 cm^3 as soil traps.

22.2.5 Climate Change Assessment and Projections

WaterWorld is a support modeling platform for simulation of hydrological systems and human impacts upon natural resources. The model is designed for application by stakeholders at the local to international scale in order to understand the baseline distribution of water and the impact of land use, land management and climate change upon the natural resource base (Mulligan et al. 2010). Within the modeling platform, Babati District was defined for the study analysis by using a one degree tile (high resolution) covering a 1 hectare resolution. The climate change simulation was for the tile with boundaries 10.0 (to the N), 9.0 (to the S), −1.0 (to the E and) −0.0 (to the W). The extreme west of the District (about 5 %) fell outside the designated tile while 95 % of the Region was captured. A baseline scenario was run which showed the current state of the system then an alternative run for water balance dynamics and climate change scenarios in the Region was conducted. The baseline run yielded mean monthly air temperature and total precipitation for each month of the year. However, only results for selected months are presented herein to highlight major trends within the annual cycle.

For each baseline, an alternative scenario was generated for water balance and climate change scenarios. The scenario characteristics for water balance estimates were based on global hydrological data sets while the climate change scenarios were based on IPCC assessments downscaled for various regions. The scenario chosen was the ‘AR4’ upgrade which includes the 2000 IPCC Special Report Emission Scenarios (SRES): uncertainty of future GHG emissions given a wide range of driving forces; no climate policies; complemented by storylines/narratives of the future; open process involving many different modeling teams (IPPC 2000). Thins study used emission scenario ‘A2 emission scenario’ which is based on the hypothesis that ‘the world evolves in a very heterogeneous way, the world

Table 22.1 Climate change scenario properties used for Babati, Tanzania

Variable	Value
IPCC assessment report	AR4
Emissions scenario	A2a
Downscaled by	CIAT
GCM name	Mean of all models plus one standard deviation
Projection year	2050s

population reaches 15 billion people in 2100, and rising, economic growth and the spreading of new efficient technologies are very different depending on the region of the world'. The GCM platform used was the mean of all models plus one standard deviation and the scenarios were projected to 2050. A summary of the scenario attributes used in this study are presented in Table 22.1.

22.2.6 Data Analysis

Forage yields, forage water productivity, runoff and soil moisture storage data were statistically analyzed with SAS V8 (2001) for two treatments factorial random block design. Since sampling was conducted on the same individuals over time (forage grasses, forage legumes and soil moisture) data were analyzed using a repeated measures model. Two factorial ANOVAs with replication were conducted to ascertain the interactions between the forage grasses and forage legumes and test if the mean values for forage water productivity, runoff and soil moisture storage were significantly different at $P = 0.05$.

22.3 Results

22.3.1 Forage Biomass and Water Productivity Trends

Farmers ranked the accessions in the following order: KK2, ILRI 16837 and KK1 as first, second and third best accessions on overall preference respectively. Among the three accessions, ILRI 16837 produced the highest yield (mean = 1.77 t ha^{-1} (DM); sd = 0.93). The number of tillers showed a significant ($P < 0.05$) positive relationship with dry matter yield for all the 3 accession forage grass–forage legume combinations. A two way factorial ANOVA analysis revealed that there were significant differences in overall dry matter results of the three forage grass and forage legume combinations.

As depicted in Table 22.2, considering the forage legumes analysis, the F distribution results revealed that $F(2,18) = 10.58$, $P < 0.05$ and P value (0.001) is <0.05 hence we showing that forage legumes had a significant difference on the

Table 22.2 ANOVA results for forage grass–forage legume dry matter harvest combinations for 2014–2015

Source of variation	SS	df	MS	F	*P* value	F critical
Forage legumes	34.991	2	17.496	10.582	0.001	3.555
Forage grasses	46.796	2	23.398	14.153	0.0002	3.555
Interaction	14.524	4	3.631	2.196	0.110	2.928
Within	29.758	18	1.653			
Total	126.070	26				

outcome of the dry matter biomass. The forage grasses analysis showed F distribution results of $F(2,18) = 14.15$, $P < 0.05$ and P value (0.0002) is <0.05 hence showing that forage grasses also had a significant difference on the outcome of the dry matter biomass with less than 0.09 % chance of getting these values by a random chance. The forage grass–forage legume interactions the F distribution results revealed: $F(4, 18) = 2.196$, $P < 0.05$ and P critical value (0.110) is >0.05, additionally, the F critical value (2.928) is >than the F value (2.196) (Table 22.2); revealing that forage grasses–forage legume interactions did not have a significant effect on the outcome of the dry matter biomass yields.

Water productivity statistical analysis (Table 22.3) for forage legumes analysis, the F distribution results revealed: $F(2,24) = 109.64$, $P < 0.05$ and P value is <0.05; F critical value (3.403) is less than the F value showing that forage legumes had a significant effect on the outcome of the water productivity results. The trends in Fig. 22.3 revealed that both KK2 and ILRI 16827 were superior to KK1 with the Desmodium legume combinations. Water productivity statistical analysis (Table 22.3) indicate that forage grasses and the forage grass–forage-legume interactions had significant influence on the water productivity results. Clearly graphical trends (Fig. 22.3) depict that KK2 and KK1 were superior to ILRI 16827 with both the Lablab and sole components over the two year period. On the overall, the Napier-Desmodium combination performed better than the Napier-Lablab combination which in turn outperformed the sole forage grass.

Table 22.3 ANOVA results for forage grass–forage legume water productivity combinations for 2014–2015

Source of variation	SS	df	MS	F	*P* value	F critical
Forage legumes	0.754	2	0.377	109.636	8.5E−13	3.403
Forage grasses	3.613	3	1.204	350.240	6.13E−20	3.009
Interaction	0.276	6	0.046	13.362	1.26E−06	2.508
Within	0.083	24	0.003			
Total	4.725	35				

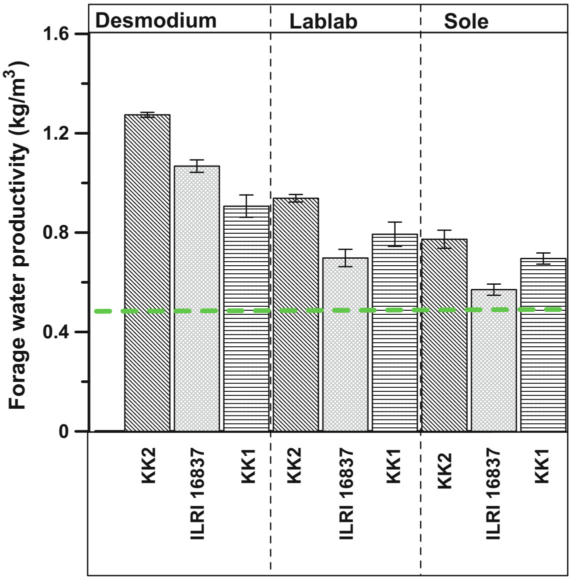

Fig. 22.3 Mean water productivity trends among forage grass–forage legume combinations for 2014 and 2015. Note the *green dotted line* as the global average threshold for forage water productivity (Sala et al. 1988)

22.3.2 Runoff and Soil Moisture Storage Dynamics in Forage Trials

Runoff results (Fig. 22.4) indicated that there were significant differences between the forage grass–forage legume combinations and the control. The control had significantly higher runoff regimes (>60 %) than the grass–legume combinations over the 2 year period. Likewise, sole Napier accessions showed significantly higher runoff levels than the Napier-Desmodium and Napier-Lablab combinations. The differences between Napier-Desmodium and Napier-Lablab (Fig. 22.4) in runoff control were not easily discernible though Desmodium registered slightly lower runoff values.

The two-way ANOVA analysis (Table 22.4) for forage legumes had F distribution results with $F(2,24) = 118.56$ at $P < 0.05$ yet the P value is much smaller than 0.05 and the F critical is less than the F value hence revealing that forage legumes had a significant effect on the outcome of the mean annual runoff. Considering the forage grasses analysis, the F distribution results revealed: $F(2,24) = 3799$ at $P < 0.05$ yet the P value is much smaller than 0.05 and the F critical is less than the F value hence revealing that forage grasses too had a significant effect on the outcome of the mean annual runoff. The forage grasses–forage legume interactions as well depicted that they had a significant effect on the mean annual runoff.

There were differences observed in soil moisture storage among the forage grass–forage legume combinations. Results indicate that the combination of KK2-Desmodium had significantly higher soil moisture storage than the other

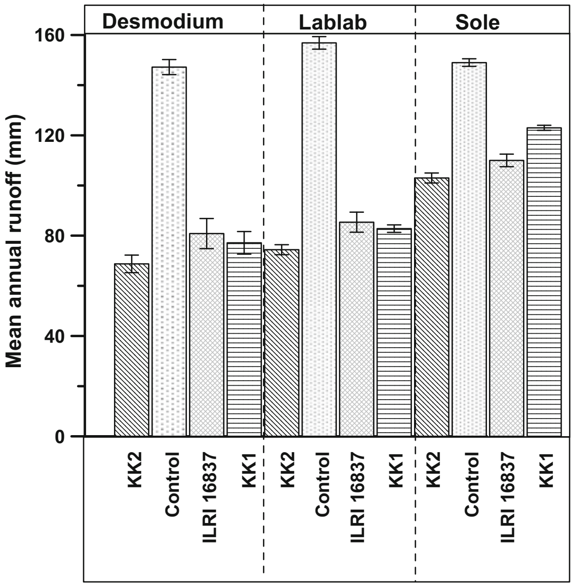

Fig. 22.4 Runoff trends among forage grass–forage legume combinations over 2 years 2014 and 2015

Table 22.4 ANOVA results for forage grass–forage legume mean annual runoff for 2014–2015

Source of variation	SS	df	MS	F	*P* value	F critical
Forage legumes	683.298	2	341.649	118.562	3.63E−13	3.403
Forage grasses	32,845.070	3	10,948.360	3799.406	2.98E−32	3.009
Interaction	320.849	6	53.475	18.557	6.15E−08	2.508
Within	69.158	24	2.882			
Total	33,918.380	35				

combinations. The two-way ANOVA results (Table 22.5) for forage legumes analysis had F distribution results with $F(2,24) = 75.48$ at $P < 0.05$ yet the P value is much smaller than 0.05 and the F critical is less than the F value hence revealing that forage legumes had a significant difference on the mean soil moisture storage. Considering the forage grasses analysis, the F distribution results revealed: $F(3,24) = 1342$ at $P < 0.05$ yet the P value is much smaller than 0.05 and the F critical is less than the F value indicating that forage grasses too had a significant effect on the soil moisture storage. The forage grasses–forage legume interactions as well depicted that they had a significant impact on the mean soil moisture storage.

Table 22.5 Two way ANOVA with replication for forage grass–forage legume soil moisture storage for 2014–2015

Source of variation	SS	df	MS	F	*P* value	F critical
Forage legumes	150.967	2	75.483	39.559	2.53E−08	3.403
Forage grasses	4026.958	3	1342.319	703.489	1.64E−23	3.008
Interaction	319.973	6	53.328	27.948	1.06E−09	2.508
Within	45.794	24	1.908			
Total	4543.692	35				

22.3.3 Climate Change Assessments

Both temperature (Fig. 22.6) and rainfall trends (Fig. 22.7) for the region revealed that there was a significant increase in the regional temperature and rainfall amounts respectively. For example, model results revealed that the total monthly rainfall is projected to have a 10 % increase in February and comparisons between the annual results for the alternative 2050s scenario and baseline conditions revealed that there would be a mean precipitation increase of about 360 mm/year. Beside the increment in amount for each month, there was about 15 % higher increment reported for non-conventional rainfall months (Fig. 22.7).

Results of the General Circulation Models (GCM) used by OECD indicated that the temperature will rise by 2 °C by 2050. The highest increase in temperature will be during the cooler period, June–August and lower in the warmer period Dec–Feb as depicted in the Table 22.6. Initial assessments by the Tanzania Adaptation Team indicate that there will be an increase in daily mean temperature by 3–5 °C throughtout the country and an average annual mean increase by 2–4 °C (Tanzania Adaption Team 2006).

Predictions of changes in rainfall are less certain with very pronounced differences among the different GCM models. However an increase of about 10 % is the most commonly accepted value. According to OECD, the distribution will also be uneven, with a 6 % predicted decrease in Jun–Aug and a 17 % increase in Dec–Feb. Changes will not be distributed accordingly over the whole country however, some parts will receive an increase while other parts a decrease. Changes will not occur in the same time and timing and intensity of rains will be less predictable (Häckner 2009). Changes in rain season patterns could also be significant, in the northern parts, the amount of rain during the short rain period could increase by 25–

Table 22.6 Estimated temperature changes in Babati based on GCM (Agrawala et al. 2003; Maddison 2007)

Year	Temperature changes				
	Annual	Jun–Aug	Sept–Nov	Dec–Feb	Mar–May
2030	0.9	1.0	0.8	0.8	0.9
2050	1.3	1.5	1.2	1.1	1.3

60 % and the amount in the long rain period by 20–45 %. The distribution of increased rain may also be uneven with an increase during the long rain period and a decrease of the short rains (Häckner 2009).

22.4 Discussions and Conclusion

The overarching message of this study is that the forage-environment-human nexus is important but under-researched and that huge opportunities exist to improve the productivity of water associated with forage production. Peden et al. (2007) illustrated that water that is used to produce 1 kg of dry animal feed through evapotranspiration is highly variable, ranging from about 0.5 to 8 kg m^{-3}. Many factors affect the amount of water depleted through evapotranspiration, including the vegetative leaf area index, root depth, rainfall, plant genetics, soil structure, moisture, and soil nutrient composition. The forage yield and forage productivity results (Tables 22.2 and 22.3) indicated that both grasses and legume combinations with Napier had a significant contribution to overall biomass yield and productivity. Sala et al. 1988 analyzed 9500 sites throughout the central United States and found that the water productivity of diverse temperate grasslands receiving 200–1200 mm of annual rainfall was similar, at about 0.5 kg of aerial biomass per cubic meter of evapotranspiration, with productivity slightly higher in wetter sites than in drier ones. The forage water productivity in this study was above the 0.5 kg m^{-3} threshold, the higher levels of water productivity are potentially because the cumulative evapotranspiration was measured only during plant growth without representing year-round calculations of evapotranspiration (Table 22.7).

In Babati, an area with inherently low biomass landscapes, the ability to produce sufficient forage products while simultaneously sustaining the natural resource base (soil, water, air and biodiversity) is a key issue confronting the future farming practices. Thus improving productivity and reducing the existing wide gap between actual and maximal forage yields will contribute towards alleviating food insecurity through enhancing forage production with suitable forage grass–forage legume combinations.

Drawing on results from field measurements, we demonstrate that forage–water interactions serves as an entry point to better understand the wider dimensions and complexity of agricultural water use in resource scarce landscapes. We thus invoke

Table 22.7 Estimated rainfall changes in Babati based on GCM (Agrawala et al. 2003; Maddison 2007)

Year	Precipitation changes				
	Annual	Jun–Aug	Sept–Nov	Dec–Feb	Mar–May
2030	4.1	−2.4	3.9	6.6	2.2
2050	5.9	−3.5	5.6	9.6	3.1

the Sustainable Intensification Indicators framework using both quantitative study results as well as qualitative assessments to deduce synergies and associated tradeoffs in a bid to minimize any unintended negative consequences in future work. The in-depth understanding of these interactions if explored with the sustainable intensification indicators framework will help to explore alternative options for improving the use of scarce water, soil and feed resources. Because forage water productivity is a function of both forage biomass yield and water input, there is a need to consider practical avenues for enhancing forage biomass alternatives along with water use efficiency in a manner that is more compatible to the specific local contexts.

The sustainable intensification indicators framework aims at providing a synthesized list of sustainable agricultural intensification (SI) indicators and metrics, categorized into five domains (economic, human condition, environmental, social and productivity) (Fig. 22.8) and three scales (field farm/households, and landscape). Regardless of the size of the land area covered, water enters an agricultural system in the form of rain or surface inflow. Water is depleted or lost through transpiration, evaporation, and runoff and cannot be readily used again. Runoff results (Fig. 22.4) and soil moisture storage trends (Fig. 22.5) clearly demonstrate that introducing management practices such as cover crops (Desmodium and lablab) that promote beneficial evapotranspiration or infiltration of available water will likely increase forage water productivity (Fig. 22.3). The forage legumes not only target rapid early growth to shade the soil and reduce evaporation but also improve

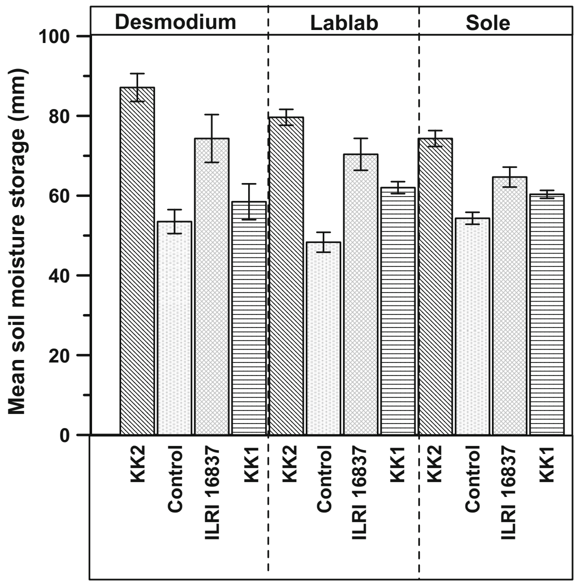

Fig. 22.5 Mean soil moisture storage trends among forage grass–forage legume combinations over 2 years 2014 and 2015

the nutritional quality of forage (Descheemaeker et al. 2009). Nyambati et al. (2003) and Kabirizi et al. (2007) reported that these forages contribute to soil fertility through the fixation of atmospheric N while serving as an excellent food source.

The case example drawn from Babati highlights a specific production system and the need for integrated site-specific interventions to ensure that agricultural production contributes to sustainable and productive use of water resources and to improved livelihoods of the poor. Study results demonstrated that lessening non-productive evaporation is possible through the use of forage legumes acting as cover crops, enhancing soil infiltration and increasing soil storage thus reducing irrecoverable deep percolation and surface runoff (Figs. 22.4 and 22.5; Tables 22.4 and 22.5). For this study, both the productivity and environmental domains of the SI indicators pentagon showed synergistic linkages. The forages are easy to establish and fast growing hence not only provide sufficient biomass for fodder but also have the capacity to stabilize land and gullies (Magcale-Macandog et al. 1998), thereby leading to water conservation as well. The aforementioned quantitative data on forage grass–forage legume combinations in relation to biomass and water productivity depicts that the productivity component of the SI indicator framework is strong (Fig. 22.8). Similarly, the runoff and soil moisture storage trends clearly depict the strength of having forage interventions within farming landscapes to reduce on soil erosion losses and downslope sedimentation while enhancing soil water infiltration, aspects that are strong in the environmental domain of the SI indicators pentagon (Fig. 22.8).

We surmise that if farmers conduct forage production with a business lens, then the economic domain could be more pronounced and would follow the green trajectory depending on the external prevailing factors such as policy, market structures and cultural preferences (Fig. 22.8). Additionally, innovative use of dual purpose cover crops such as cowpea (*Vigna ungulata*) (Tarawali et al. 1997; Singh et al. 2003) could provide higher nutritional benefits for household consumption in addition to serving as fodder for livestock. This would potentially follow the red trajectory (Fig. 22.8) to increase the human domain of the SI indicators pentagon. The role that forage–grass and forage legumes combinations (Napier-Desmodium and Napier-Lablab) play towards improving the nutritive value of fodder cannot be underestimated (Zhang et al. 2009). Adding these sources of nutritive fodder to Napier grass as animal diets improve feed conversion and increase digestibility (Descheemaeker et al. 2009) hence reducing methane emissions from enteric fermentation (Herrero et al. 2008) thus providing positive outcomes on the environmental domain of the SI framework (Fig. 22.8) through climate change mitigation. This may in turn increase resilience and adaptive capacity of smallholder farmers (an aspect that would enhance the under-represented social domain in Fig. 22.8).

In semi-arid environments up to 90 % of rainfall evaporates back into the atmosphere, leaving just 10 % for productive transpiration. Micro- and macro-catchment management techniques that can capture more of this water such as use of forage grass and forage legume cover crop combinations for subsequent crop use before it evaporates, increase beneficial rainwater available for transpiration to 20–50 % (Oweis et al. 1999). Agricultural water management practices can provide multiple ecosystem services beyond food production. For example, the value of forage legume and forage grass combinations is underestimated unless its multifunctional roles are taken into consideration. These practices reduce environmental costs and enhance ecosystem services increase the value derived from agricultural water management (Matsuno et al. 2006). In rangelands, especially dry ones, forage water productivity is low, but there are few alternate uses of agricultural water, only a small part of the evapotranspiration typically attributed to pasture production is actually used by grazing animals. Typically, about half of plant biomass production takes place below ground. In well managed pastures only about half of the above biomass is consumed by grazing animals. Of the amount consumed only about half is digested, with the remainder being returned to the soil. Thus, only about one–eighth of depleted evapotranspiration contributes to animal production. The rest contributes to maintaining the pasture ecosystem and providing ecosystem services like soil health attributes (improved nutrient composition, improved soil structure, better soil moisture storage and reduced erosion impacts). These services either directly or indirectly influence the 5 domains of the SI indicators pentagon with numerous permutations of synergies and tradeoffs depending on the context at hand.

Study results indicate a steady increase in temperature and a projected increase in rainfall over the next 40 years to the 2050s (Figs. 22.6 and 22.7). A warming climate will inevitably place additional stresses on water resources, whether or not future rainfall is significantly altered. Increments in regional rainfall amounts will call for more concerted management of water resources in order to optimize agricultural productivity within the cropping cycles. It also creates opportunities for potential storage options as a coping mechanism and adaptation to climate change. Though predictions pertaining to future warming are robust, there remains

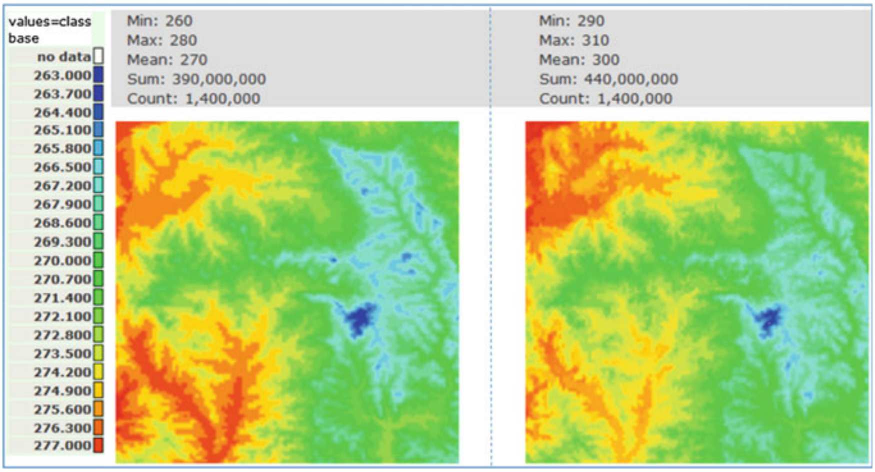

Fig. 22.6 Baseline (*left*) and 2050s scenario (*right*) mean monthly temperture (°C). *Upper greyed* tabs provide monthly statistical summaries for each simulation

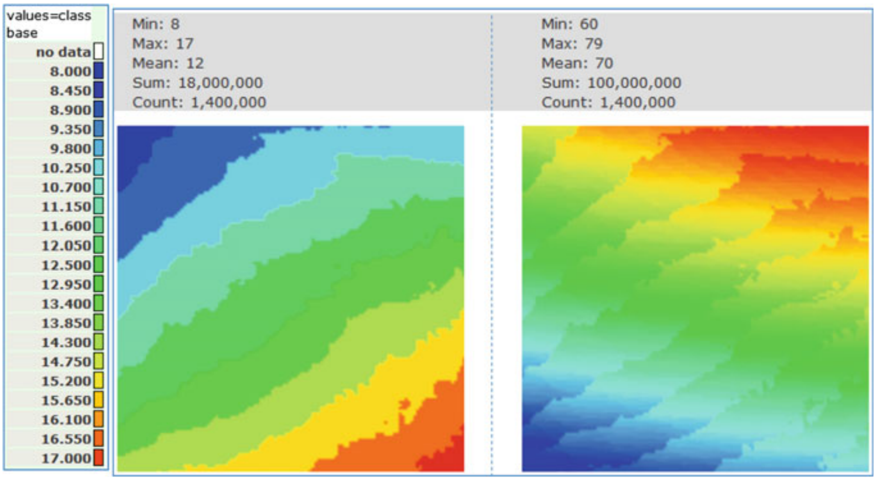

Fig. 22.7 Baseline (*left*) and 2050s scenario (*right*) total monthly rainfall for November (mm/month). *Top grey* tabs depict monthly statistical summaries for each simulation

significant uncertainty about the magnitude and direction of regional rainfall changes for the most of Africa. In their work on African climate change, (Hulme et al. 2005) surmise that there is a rather ambitious representation in most GCMs of the El Nino Southern Oscillation (ENSO)-type climatic variability in the tropics (a key determinant of African rainfall variability). This is further coupled by the omission of any representation of dynamic land cover-atmosphere interactions and dust and biomass aerosols. These relationships and interactions have been suggested to be critical in determining African climate change.

If rainfall is received in higher amounts at greater intensities over short durations, it may translate into an extreme event in an area that is prone to flooding. The impacts of extreme events on many developing countries have been reported to likely be negative (Low 2005). Therefore, efforts should be directed towards reducing the rate of change (mitigation) or manage its consequences (adaptation). Depending on how climatic changes unfold, and how local communities in Tanzania mitigate or adapt to these changes, a significant number of people could be at risk from extreme events such as floods which may further lead to negative social externalities and hunger. The identification of pathways for adaptation should form a key feature of the development landscape. Identification of local, institutional, knowledge and policy gaps that may constrain effective response to climate change and how the use of science, technology and innovation may be targeted to bridge these gaps in future and enhance community adaptation strategies. These would strengthen the social domain in the SI indicator pentagon presented in Fig. 22.8. Finally, a deeper understanding of the ecological consequences of more extreme intra-annual precipitation patterns will also strengthen our knowledge of vegetation–climate relationships and how forage legumes and forage grass

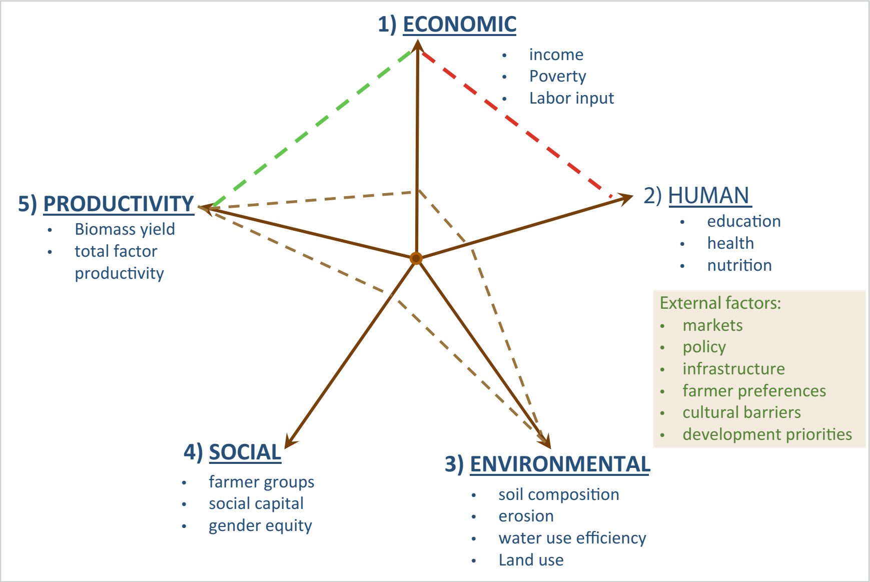

Fig. 22.8 Representation of the forage system synergies and tradeoffs (*dotted brown lines*) along a sustainable intensification indicators framework with five core domains and some indicators for each domain. Potential trajectories of change are shown in *green* and *red dotted lines* (adapted from Africa RISING Sustainable Intensification Workshop, Accra, July 2013)

combinations can help reduce some negative impacts associated with climate change at farm level and catchment scales.

Additional research is needed to further scale and test the findings highlighted in this study to fill critical knowledge gaps in our understanding of ecological responses from farm level to landscape scales in the context of water balance dynamics within forage systems. We suggest that future research focuses on the need for (a) enhanced documentation and projection of intra-annual precipitation patterns at local and regional scales; (b) greater insight into the direct effects of these modified rainfall delivery patterns on agricultural productivity, ecosystem structure and function, as well as interactions with other regional and global change drivers; and (c) greater understanding of how modifying the dynamics of the ecosystem water balance may impact forage production and vice versa. There is a clear need for field experimentation combined with systems modeling to address these under-studied components. Key to these experiments is greater knowledge of exactly how precipitation regimes are changing and how much they can be expected to change in the future and their impact on agroecosystem productivity including forages. Finally, a deeper understanding of the ecological consequences of more extreme intra-annual precipitation patterns will also strengthen our knowledge of vegetation-climate relationships and anthropogenic feedbacks at both farm level and catchment scales.

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