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Farm-scale assessment of maize–pigeonpea productivity in Northern Tanzania

E. Mugi-Ngenga · S. Zingore · L. Bastiaans · N. P. R. Anten · K. E. Giller

Abstract Little is known about productivity of smallholder maize–pigeonpea intercropping systems in sub-Saharan Africa. We conducted a survey of 277 farm households in Northern Tanzania to assess socio-economic factors, field management characteristics, and their association with productivity of maize–pigeonpea intercrops. On each farm, crop assessments were focused on a field that the farmer identified as most important for food supply. Variables associated with yields were evaluated using linear regression and regression classification. Biomass production ranged between 1.0 and 16.6 for maize, and between 0.2 and 11.9 t ha^{-1} for pigeonpea (at maize harvest). The corresponding grain yields ranged between 0.1 and 9.5 for maize, and between 0.1 and 2.1 t ha^{-1} for pigeonpea. Plant density at harvest, number of years the field had been cultivated, slope, weeding, soil fertility class, fertiliser and manure use were significantly associated with variation in maize grain yield, with interactions among the factors. Fields on flat and gentle slopes with plant density above 24,000 ha^{-1} had 28% extra yields when fertiliser was applied, while less than 24,000 plants ha^{-1} yielded 16% extra yield when manure was applied. Plant density at harvest was the key factor associated with pigeonpea yield; fields with densities above 24,000 plants ha^{-1} yielded an average of 1.4 t ha^{-1}, while less than 24,000 plants ha^{-1} yielded 0.5 t ha^{-1}. We conclude that performance of intercrops can be enhanced through application of organic and inorganic nutrient sources, and agronomic interventions including weeding, implementing soil conservation measures on steep slopes and optimising plant density.

Keywords Smallholder farms · Plant density · Intercrops · Fertiliser · Manure · Soil fertility

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Introduction

Crop production in smallholder farming systems of the East African highlands is dominated by maize, which is the main staple and a food security crop (Arias et al. 2013). Intercropping of maize with grain legumes mainly pigeonpea, beans, dolichos lablab and cowpea is common (Kimaro et al. 2009; Massawe et al. 2016; Myaka et al. 2006; Ndungu-Magiroi et al. 2017). Such intercrops form the basis of smallholder family food security and are crucial for economic growth (Myaka et al. 2006). Legumes provide multiple benefits in intercrops in addition to the legume grain, both in the current and subsequent seasons. These include increase in availability of N from nitrogen (N_2) fixation, reduction in occurrence of pests and diseases, extended ground cover, better rooting ability, improved soil fertility and increase in maize yields (Giller 2001; Li et al. 2013; Mucheru-Muna et al. 2010; Yu et al. 2015; Zhang et al. 2019).

Pigeonpea is well suited for intercropping with maize as it has an initial slow growth, avoiding competition with the primary maize crop (Silim et al. 2005). Pigeonpea has a longer growth cycle, and when sown simultaneously can continue to grow for up to three months after maize harvest (Myaka et al. 2006). The extended period of growth ensures that the greatest demand for water and nutrients in pigeonpea occurs after maize has been harvested (Dalal 1974). The relatively deep root system enables pigeonpea to exploit moisture from deeper soil layers, effectively withstanding the dry conditions encountered at later stages of growth (Kumar Rao et al. 2001). In addition to direct consumption of green pigeonpea pods for food, there is a good market for the dry grain (Löfstrand 2005). Pigeonpea has developed into an important cash crop in East and southern Africa which is mainly exported to India (Silim et al. 2005). After harvest, pigeonpea stems are used as firewood, which is a scarce resource in many areas of Tanzania (Adu-Gyamfi et al. 2007; Myaka et al. 2006). Furthermore, seed costs are low partly because farmers can retain seeds from the previous season (Sakala et al. 2003). Thus, maize–pigeonpea intercrops provide multiple benefits with minimal additional labour (Myaka et al. 2006).

In Northern Tanzania, pigeonpea is frequently intercropped with maize, yet major gaps exist in the understanding of the characteristics of maize–

pigeonpea intercropping systems and the key factors associated with their productivity. An agronomic survey by Kihara et al. (2015) assessed crop yield, controlling factors and management implications, where only maize crop was directly monitored through field measurements. Other studies have focused on limited components of the intercrops, including comparing maize–pigeonpea intercrops to sole maize in terms of yields and nutrient accumulation (Myaka et al. 2006), characterisation of only the pigeonpea crop (Silim et al. 2005), quantifying the amount of atmospherically-derived N fixed by different pigeonpea varieties intercropped with maize (Adu-Gyamfi et al. 2007) or effects of competition between maize and pigeonpea on yields and nutrition of the crops (Kimaro et al. 2009). Owing to the potential complementarity of maize and pigeonpea in intercrops, our aim was to examine whether maize grain yield would be greater when intercropped with pigeonpea than in other intercrops, and whether factors associated with the yields were region-specific. To investigate this, we conducted a farm level agronomic survey to: (1) understand the socio-economic setting, structural and biophysical characteristics of farms and farming households across regions in Northern Tanzania, (2) assess the current field management and productivity of maize–pigeonpea intercrops and (3) explore factors that are associated with productivity of maize–pigeonpea intercrops.

Methods

Study site

The study was conducted in the Northern Highlands Zone of Tanzania covering Arusha, Kilimanjaro and Manyara regions (Online Resource 1). The sampled area lies between 3° and 5° South latitude, 35° and 37° East longitude, and elevation within the ranges from 685 to 1920 m above sea level. The annual precipitation pattern is typically bi-modal: there being a relatively long rainy season (locally known as *Masika*") from March-July and a shorter one ("*Vuli*") from October-December. The mean seasonal rainfall in the 2016/2017 growing season was 474 mm, 434 mm and 387 mm in Kilimanjaro, Arusha and Manyara respectively. Temperature ranged from 20 to 28, 19–26 and 18–25 °C with means of 24, 22 and 21 °C in

Kilimanjaro, Arusha and Manyara respectively (https://power.larc.nasa.gov/data-access-viewer/). Predominant soil types range from well-drained humic nitosols to soils of volcanic origin (sandy loams to clay alluvial soils) (Mowo et al. 2006).

Sampling and farming systems characterization

Farm households interviewed were randomly selected following the stratified random approach developed by Africa Soil Information Service (AfSIS) (Huising 2012). First twelve districts were selected (3 in Arusha, 5 in Kilimanjaro and 4 in Manyara), within which a randomly selected 10,000 × 10,000 m grid was established per district. Then, within each of these 10,000 × 10,000 m grids, three 1,000 × 1,000 m clusters (wards) were randomly selected, where all farm households involved in farming were listed. Thereafter, within each cluster, eight farm households were randomly chosen. This translated into a sample size of 24 farm households per district (3 clusters × 8 farm households), giving a total of 288 farm households.

Comprehensive data was collected using a semi-structured questionnaire in the form of an open data kit (ODK)-based survey instrument, with the help of well-trained agricultural officers. Data collection involved first drawing a sketch of the farm with help of the farmer. Subsequently, all plots that were cultivated by the household during the 2016/2017 main agricultural season were numbered, and this coincided with the time the survey was conducted. Basic information on crops and production was collected for each plot managed by the household. In addition, the farmer was asked to identify the most important plot for food supply at household level, as maize is the predominant staple crop (Kaliba et al. 2000). The selected plot was treated as the focal plot from which very detailed agronomic management information was collected. Although our sampling strategy was fully randomised at the farm level, the plot for which information was collected was not sampled randomly. We chose to do this for two related reasons: First, it was not possible to collect such detailed information from all of the fields of each farm. Secondly, a purely random sampling would have led to selection of fallow land, or a field that was not being intensively managed as it is common that farmers plant a larger area than they are able to manage intensively. Earlier studies in East

and southern Africa have identified strong spatial gradients of declining soil fertility with distance from the household due largely to allocation of animal manures to specific plots (Baijukya et al. 2005; Tittonell et al. 2005; Zingore et al. 2007). By contrast, little cattle manure is applied to fields in the study area, and these are also less intensively managed and no strong spatial patterns of soil fertility are observed such that we do not anticipate that this plot selection strategy introduced strong bias. We acknowledge that the non-random sampling of fields within the farms may introduce some bias which we cannot quantify.

Design of the questionnaire and topics were informed by literature review (Kihara et al. 2015; Mugwe et al. 2008; Silberg et al. 2017; Waithaka et al. 2007), and factors investigated were those commonly associated with yields and the agricultural practices under study. Farm-household information was obtained based on current data within the 2016/2017 main agricultural season. This included standard socio-economic and structural characteristics (age, gender, marital status and education level of household head, land size, household size, livestock ownership and extension service access). Focal plot information was based on current data and direct monitoring/measurements targeting crops grown in the 2016/2017 main agricultural season. Crop cuts and soil samples were taken from these focal plots. Within each focal plot, three 5 m × 5 m square quadrats (centre and two corners) were demarcated to act as replicates. Information collected from the focal plot included weeding frequency, seed type used, distance from homestead, fertility level, slope, use of irrigation, fallow in the past 10 years, years the land had been under cultivation, GPS readings, fertiliser and manure use (Online Resource 2). From each quadrat of the focal plot (each focal plot had three quadrats), information on number of maize plants and maize cobs, number of pigeonpea plants (where present), plant spacing, number of plants per stand of maize and pigeonpea (where plants were planted in rows) and stage of development of pigeonpea at maize harvest (e.g. flowering or podding) was recorded. Thereafter, destructive sampling was done per quadrat, where three plants each for maize and pigeonpea were taken for determination of yield and yield components. To estimate maize production, measurements per quadrat involved separating cobs from stover and weighing the components separately. Thereafter, a sample of three

cobs was taken (ensuring that they represented the sizes and moisture content of all the cobs), to be used in estimating maize grain yields. Maize stover was then chopped and weighed in the field, and a sub-sample taken. For pigeonpea, fresh weight of the selected plants from each of the 5 m × 5 m square quadrats was measured, the plants were chopped in the field, and a weighed sub-sample taken (the crop was either in the flowering or podding stage). Apart from maize cob sub-samples from the different quadrats which were considered separately (3 cobs from each quadrat considered as independent samples), other sub-samples from the three different quadrats were bulked to form a composite sample (Online Resource 3). The sub-samples were oven dried at 75 °C for 48 h (stover) or 72 h (grains) for determination of dry weight at Tanzania Agricultural Research Institute (TARI)-Selian, Arusha-Tanzania. To assess pigeonpea productivity after maize harvest, grain yields were monitored in the same quadrats where biomass measurements and management information had been taken when the crop attained physiological maturity. Whereas measurements for maize biomass and grain yield were taken in all fields where crop cuts were possible, pigeonpea yields were monitored from a proportion of fields (randomly sampled), due to labour limitations. This sample represented a third of the fields where pigeonpea biomass and management information had been taken previously.

Soil samples were collected when maize crop was at physiological maturity and pigeonpea was at reproductive stage (flowering/early podding). This was done using an auger from each quadrat (0–0.2 m) by taking two sub-samples from representative field positions comprising two corners of a quadrat. The sub-samples were then mixed to form a composite sample per quadrat. This was repeated in the other two quadrats, ending up with three composite samples (one for each quadrat). Finally, the three composite samples were bulked and a sample representative of the focal plot drawn for laboratory analyses. Soil samples were air-dried, passed through a 2 mm sieve and ground to < 0.5 mm before analysis. Analyses were conducted by loading samples into micro-soil cups, scanning samples using alpha mid-infrared diffuse reflectance spectroscopy (MIR, 2.5–25 μm) and finally spectral prediction into various soil properties. Soil properties estimated included total carbon (C) and nitrogen (N) contents; available phosphorus (P); soil pH;

exchangeable potassium (K), calcium (Ca) and magnesium (Mg) concentration (Table 1). Calibration samples were analysed by combustion method (for C and N), Electrodes (pH) and Mehlich 3 extraction (P, K, Ca and Mg) (Vagen et al. 2010). Processing and analyses of the samples was done at TARI-Selian, Arusha-Tanzania.

Data analysis

To understand the current biophysical factors and assess the current field management and productivity of maize–pigeonpea intercrops across regions in Northern Tanzania, box plots and cumulative probability was used. Analysis of variance (ANOVA) was performed to test for differences in soil variables, biomass and grain yield among regions. Where a difference was significant, least significant difference test (LSD test) was used to separate means using the *agricolae* package (R Core Team 2019).

To assess the association of field management factors with productivity of maize–pigeonpea intercrops, we modelled factors associated with maize and pigeonpea yields using a linear model and the *lm* function (R Core Team 2019). The dependent variable was maize or pigeonpea grain yield and independent variables were field-specific characteristics and management factors. These included plant density at harvest, years the land has been under cultivation, slope, distance from homestead, weeding frequency, seed variety, fertility level, fertiliser and manure use. Factors which were found to be consistent across all sampled fields were not included in the model. This included irrigation which was not practiced in any field. Since the study was conducted in three sampling regions with varying rainfall and temperature conditions, the model was executed based on each sampling region. However, the statistical analyses per region was only possible for maize and not for pigeonpea. This was because contrasts can only be applied to independent categorical factors with two or more levels, and some of the factors for pigeonpea had only one level when considered on a regional basis. To further understand factors associated with maize grain yields, we classified the yields under different management options using regression classifications (Kihara et al. 2015; Tittonell et al. 2008), with ANOVA as the method of creating splits and the *rpart* function (R Core Team 2019). Variables used were specific to the

Table 1 Concentrations of key nutrients in the top soil (0–0.2 m) in Northern Tanzania (total $n = 284$)

Region	Soil properties							
	pH (water)	C (%)	N	P (mg kg^{-1})	K (mmol kg^{-1})	Ca	Mg	EC dS m^{-1}
Arusha ($n = 72$)	6.51$_a$	1.04$_a$	0.06$_a$	6.87$_b$	7.03$_a$	72.85$_a$	21.44$_a$	64.80$_b$
Kilimanjaro ($n = 119$)	6.17$_c$	1.08$_a$	0.07$_a$	9.54$_a$	3.61$_b$	46.70$_b$	15.38$_b$	76.48$_a$
Manyara ($n = 93$)	6.37$_b$	0.77$_b$	0.05$_b$	7.23$_b$	4.41$_b$	44.54$_b$	16.16$_b$	54.86$_b$

Means followed by different letters in the same column are significantly different at $p < 0.05$

analysis conducted, so the number of observations (n) in the various tables and figures vary. This variation in n resulted from missing households, farmers who had already harvested their maize before crop cuts, while soil sampling was not permitted in all farms.

Results

Socio-economic setting, field management and biophysical factors

A majority of farm households (HH) were male-headed (76–93%) (Table 2). Average household size was 5–6 persons per farm household with an average age of HH heads across the regions of 48–57 years. The majority of HH heads had attained primary level of education (68–85%) with only 6–13% being illiterate (no formal education). A majority of the HH heads were married (74–94%), with most of the remainder widowed. Average land size per household was 1.2–2.4 ha (Table 2).

Assessment of the current field management of maize–pigeonpea intercrops across regions in Northern Tanzania showed that farmers used both local and improved varieties, either recycled or purchased. For maize, a majority ($\geq$ 55%) mainly purchased seed of improved varieties, while the rest used recycled seed of local varieties (Table 2). On the other hand, a majority ($\geq$ 90%) used recycled seed of local pigeonpea varieties, and only few bought seed. Farmers adopted different planting patterns: For maize, 87% used a well-defined row spacing with only 13% planting randomly, whereas for pigeonpea, 44% used well-defined spacing while 56% planted randomly. Additionally, 11% of the focal plots that had maize–

pigeonpea intercrops had both crops planted randomly. In cases where well-defined spacing was noted at the time of sampling, inter-row spacing for maize ranged from 0.6 to 1.15 m with an average of 0.85 m, whereas intra-row spacing ranged between 0.25 and 0.75 m with an average of 0.5 m. For pigeonpea, inter-row spacing ranged from 0.5 to 1 m with an average of 0.8 m, whereas intra-row spacing ranged between 0.35 and 0.85 m with an average of 0.55 m. Planting pattern varied among regions (Fig. 1), but only significantly for maize when Kilimanjaro and Manyara regions were compared. There were no significant differences in pigeonpea spacing among regions (Fig. 1). Measurements of plant density at harvest of the two crops across regions (Fig. 2) revealed that less than 20% of the farmers had a density above 40,000 plants/ha, which is the recommended plant density for intercropped maize in Northern Tanzania (Kihara et al. 2015). Across regions, plant density at harvest ranged from 11,883 to 61,000 plants/ha for maize and 7,903 to 55,000 plants/ha for pigeonpea when crops were planted in rows. Where crops were planted randomly, plant density at harvest ranged between 5,200 and 48,800 plants/ha for maize and between less than 5,000 and 53,200 plants/ha for pigeonpea. Intercropping was practiced by all of the farmers interviewed. Intercrops included maize intercropped with pigeonpea (*Cajanus cajan*) (54%), common bean (*Phaseolus vulgaris*) (25%), sunflower (*Helianthus annuus*) (11%) and other crop mixtures (10%) of maize with lablab (*Lablab purpureus*), cowpea (*Vigna unguiculata*) and sorghum (*Sorghum bicolor*) (Fig. 3). It is notable that whereas maize–pigeonpea was well represented across regions, other intercrop systems had very few cases recorded in some regions. For instance, fewer cases of maize–bean intercrop were found in Manyara and only one case of maize–

Table 2 The socio-economic setting of farm households and variables used in the models from three regions of Northern Tanzania during the 2016 / 2017 main agricultural season

Data type	Variable	Unit	Direction	Summary statistics		
				Arusha ($n = 69$) Mean	Kilimanjaro ($n = 120$)	Manyara ($n = 88$)
Continuous	Maize/ pigeonpea grain yield	t ha^{-1}	–	–	–	–
Continuous	Density at harvest	Number of plants ha^{-1}	–	–	–	–
Continuous	HH head age	Years	–	48	57	48
Continuous	Household size	Number of persons	–	6	5	6
Continuous	Land size	ha	–	2.4	1.2	1.6
Continuous	Years under cultivation	Years	–	17	25	20
Continuous	Distance from homestead	Metres (m)	–	13,000	6000	30,000
Continuous	Weeding frequency	Numbers	–	1.3	1.5	1.7
				Proportion per region (%)		
Categorical	Gender of HH head	–	0 = female	15	24	7
			1 = male	85	76	93
Categorical	Marital status of HH head	–	0 = others	12	26	6
			1 = married	88	74	94
Categorical	Education level of HH head	–	0 = none	13	6	13
			1 = primary	68	85	78
			2 = secondary	16	5	5
			3 = post-secondary	3	4	4
Categorical	Slope	–	1 = steep	10	14	17
			2 = flat	18	26	14
			3 = gentle	72	60	69
Categorical	Fallow practice in the past 10 years	–	0 = no	81	94	97
			1 = yes	19	6	3
Categorical	Maize/ pigeonpea seed variety	–	1 = local	45 (90)	31 (100)	40 (92)
			2 = improved	55 (10)	69 (0)	60 (8)
Categorical	Fertiliser use	–	0 = no	90	59	89
			1 = yes	10	41	11
Categorical	Manure use	–	0 = no	11	78	14
			1 = yes	89	22	86
Categorical	Fertility level	–	1 = infertile	3	7	10
			2 = moderate	81	86	65
			3 = fertile	9	7	20
			4 = very fertile	7	0	5

Values in brackets are for pigeonpea seed variety

Where summary statistics is not given, this is presented in the figures

HH Household

sunflower and maize with other legumes in Arusha and Manyara respectively (Fig. 3). Assessment of management practices for improving soil fertility in the 2016/ 2017 main agricultural season showed that on average, 51% of the sampled farm households used only manure, 18% used only fertiliser, 29% used both
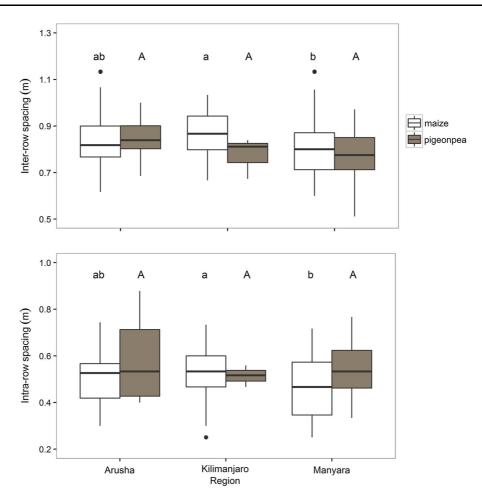
Fig. 1 Box plots showing measured inter and intra-row spacing (m) of maize and pigeonpea in the different regions of Northern Tanzania in fields where seeds were not broadcast (maize $n = 158$ out of 182; pigeonpea $n = 41$ out of 90). Within the box plots, horizontal lines represent the median, lower and upper box plot boundaries represent the 25th and 75th percentiles respectively, lower and upper whiskers represent the minimum and maximum values respectively, while dots above and below whiskers represent outliers. Mean differences in spacing at 5% significance level in the different regions are indicated with different letters on the upper side of each box plot for maize (small letters) and pigeonpea (capital letters)

manure and fertiliser whilst 2% neither used manure nor fertiliser. A majority of farmers who did not use fertiliser (51%) reported that it was not needed due to a lack of crop response, 26% lacked cash to purchase while the rest (23%) gave reasons such as the commodity being expensive and not available.

Following Hazelton and Murphy (2016) to interpret the soil test results, available P values were small (> 5–10 mg/kg) while soil carbon (C) was within a moderate range (Table 1) with significantly lower concentrations in Manyara than in the two other regions. The pH was between 6.0 and 6.5, being significantly lower in Kilimanjaro although soil acidity was not a problem in any of the regions.

Exchangeable cations were above critical values and significantly greater in the Arusha region (Table 1). We further compared our soil analysis results with farmers' own assessment of the soil fertility of their fields. Farmers used various indicators to distinguish fields as very fertile, fertile, moderately fertile or infertile. The main indicators used were production history (crop yield) of the field, soil colour and presence of certain weed species. A majority of farmers (79%) classified their soils as moderately fertile (Table 3). The pattern of measured soil properties followed that of the farmers, in that all variables decreased progressively with poorer soil fertility level,
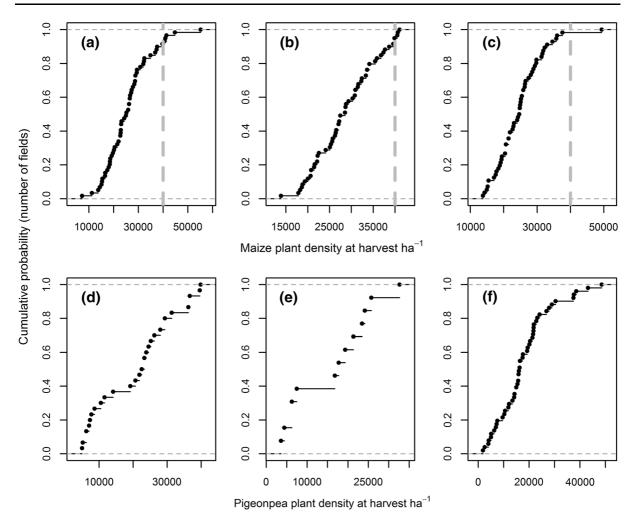
Fig. 2 Cumulative probability of maize and pigeonpea plant density in intercrops at maize harvest in the 2016/ 2017 main agricultural season across three regions of Northern Tanzania.

Maize = a, b and c in Arusha, Kilimanjaro and Manyara respectively; Pigeonpea = d, e and f in Arusha, Kilimanjaro and Manyara respectively

though the differences among levels were not significant (Table 3).

Maize and pigeonpea production

The companion species intercropped with maize (i.e., pigeonpea, common beans, sunflower or other species) had no significant effect on maize grain yield (Fig. 3). There were significant differences in maize and pigeonpea biomass and grain yields among farms and regions (Fig. 4). Maize biomass production across regions ranged from 1.0 to 16.6 t ha^{-1}, whilst pigeonpea biomass production (when measured at the time of maize harvest) ranged from 0.2 to 11.9 t ha^{-1}, with means of 4.7 t ha^{-1} and 3.5 t ha^{-1},

respectively (Fig. 4a, c). Maize biomass production in Arusha was significantly smaller than in Manyara ($P < 0.05$) while pigeonpea biomass production in Arusha was significantly greater than in Manyara ($P < 0.05$). Furthermore, at physiological maturity, mean pigeonpea biomass production across regions was 3.4 t ha^{-1} (data not presented). The corresponding maize grain yield across regions ranged from 0.1 to 9.5 t ha^{-1} (mean of 3.3 t ha^{-1}) whilst pigeonpea yields ranged from 0.1 to 2.1 t ha^{-1} (mean of 0.8 t ha^{-1}) (Fig. 4b, d). Maize grain yields were significantly greater in the Kilimanjaro region than in Arusha and Manyara, whereas no significant differences in pigeonpea yield across regions were observed.
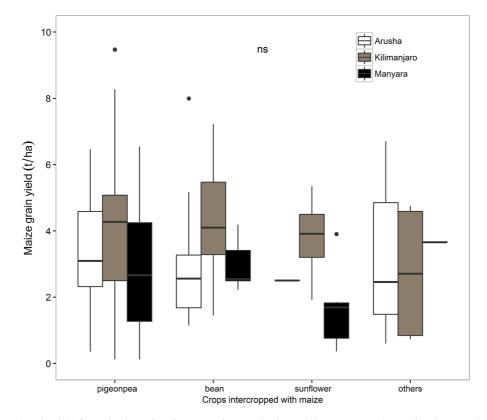
Fig. 3 Measured grain yield for maize in various intercrops in 2016/2017 cropping season in Northern Tanzania. Mean differences in grain yield in the various intercrops were not significantly different at 5% significance level as indicated on the upper side of the box plots. Number of observations across regions: maize–pigeonpea $n = 95$, maize–bean $n = 44$, maize–sunflower $n = 19$, maize–others $n = 18$. Within the box plots, horizontal lines represent the median, lower and upper box plot boundaries represent the 25th and 75th percentiles respectively, lower and upper whiskers represent the minimum and maximum values respectively, while dots above the whiskers represent outliers. "Others" refers to intercrops of maize with crops such as lablab, cowpeas and sorghum

Table 3 Soil properties in different fertility levels as per farmers' subjective evaluation (total $n = 234$)

Fertility level	pH (water)	C (%)	N	P (mg kg^{-1})	K (mmol kg^{-1})	Ca	Mg
Very fertile ($n = 8$)	6.35 (0.33)	1.23 (0.83)	0.06 (0.02)	9.60 (13.3)	4.3 (1.4)	55.9 (43.7)	19.1 (11.9)
Fertile ($n = 26$)	6.46 (0.42)	1.10 (0.60)	0.07 (0.04)	7.99 (5.09)	5.1 (3.4)	71.3 (51.6)	19.3 (12.2)
Moderate ($n = 185$)	6.31 (0.52)	0.97 (0.53)	0.06 (0.04)	7.97 (5.53)	4.8 (3.5)	52.9 (39.5)	17.5 (12.7)
Infertile ($n = 15$)	6.29 (0.48)	0.82 (0.40)	0.04 (0.02)	7.88 (4.65)	3.2 (1.9)	40.5 (22.8)	14.8 (13.5)

Values in brackets are standard deviations

All means of soil properties across fertility levels were not significantly different at $p < 0.05$

Factors associated with maize and pigeonpea production

An assessment of the association of field management factors with productivity of maize–pigeonpea intercrops showed that field characteristics (slope) and management factors (plant density at harvest, years under cultivation, weeding frequency, fertility level, seed variety used, fallow practice, fertiliser and manure use) were significantly associated with maize
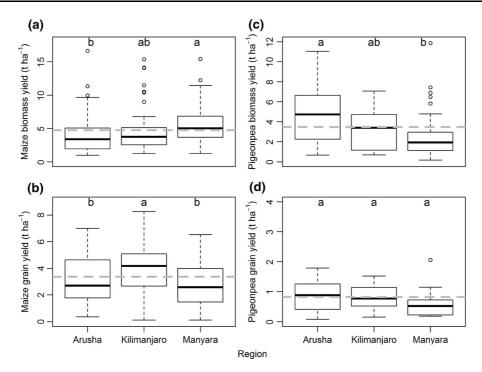
Fig. 4 Measured biomass production for maize and pigeonpea (a and c) and grain yields for maize and pigeonpea (b and d) in 2016/ 2017 cropping season in three regions of Northern Tanzania (biomass measurements taken at maize harvest). Mean differences in biomass and grain yield at 5% significance level in the different regions are indicated with different letters on the upper side of each box plot. The horizontal dotted lines represent mean biomass and grain yield across regions. For biomass yield: Arusha; maize $n = 57$, pigeonpea $n = 28$; Kilimanjaro; maize $n = 55$, pigeonpea $n = 13$; Manyara; maize $n = 56$, pigeonpea $n = 49$). For grain yield: Arusha; maize $n = 59$, pigeonpea $n = 9$; Kilimanjaro; maize $n = 61$, pigeonpea $n = 11$; Manyara; maize $n = 56$, pigeonpea $n = 11$. Within the box plots, horizontal lines represent the median, lower and upper box plot boundaries represent the 25th and 75th percentiles respectively, lower and upper whiskers represent the minimum and maximum values respectively, while dots above the whiskers represent outliers

grain yields (Table 4), and plant density at harvest for pigeonpea grain yield (Table 5). Larger plant density at harvest resulted in greater maize and pigeonpea grain yields across regions. Maize yields declined with increasing number of years the field had been under cultivation in Arusha, where each additional year resulted in an average yield decline of 0.03 t ha^{-1}. In Arusha and Manyara, fields on gentle slopes had greater maize grain yields of 1.24 and 1.27 t ha^{-1} respectively, over yields on steep slopes. Weeding frequency had a positive effect on maize yields in Manyara region, where every additional weeding event resulted in a yield increase of 0.56 t ha^{-1} Manure application had a positive and significant impact on maize grain yields in Manyara, where its addition increased yield by 1.92 t ha^{-1}. Additionally, fertiliser use had a positive and significant impact on maize grain yields (Table 4), where its addition increased yield by 1.54, 1.62 and 1.17 t ha^{-1} in

Arusha, Kilimanjaro and Manyara respectively. Yields on fields that farmers rated as very fertile in Arusha obtained an extra 2.59 t ha^{-1} over yields on infertile fields. Fields where improved maize seed variety was used recorded a 0.84 t ha^{-1} more yield over local seed variety in Arusha, while fallow practice in the past ten years resulted in 1.06 t ha^{-1} increase in yields in Manyara region.

Classification trees were used to further understand the interaction of various factors associated with maize yields. Results showed that although maize grain yields on steep slopes were significantly smaller than on flat and gentle slopes, distance from the homestead also explained a proportion of these patterns. Yields on more steep slopes that were less than 3500 m from the homestead produced 55% more yields than those that were more than 3500 m from the homestead (Fig. 5). Similarly, yields on flat and gentle slopes with plant density below 24,000 plants ha^{-1} had

Table 4 Mixed-effects model parameters for the management factors associated with maize grain yield in three regions of Northern Tanzania during 2016/2017 main agricultural season

Independent variables	Arusha			Kilimanjaro			Manyara		
	Estimate	S.E.	Sig	Estimate	S.E.	Sig.	Estimate	S.E.	Sig.
Density at harvest (plants ha^{-1})	**0.00009**	0.00002	< 0.001	**0.0001**	0.00005	0.03	**0.000001**	0.00002	0.04
Years under cultivation (years)	**− 0.03**	0.01	0.02	− 0.02	0.02	0.19	− 0.007	0.009	0.46
Slope: flat	0.78	0.63	0.22	0.45	1.08	0.68	0.33	0.46	0.48
Slope: gentle	**1.24**	0.58	0.04	0.61	1.08	0.58	**1.27**	0.31	< 0.001
Distance from homestead (m)	− 0.006	0.008	0.42	− 0.03	0.04	0.38	− 0.001	0.006	0.84
Weeding frequency (numbers)	0.007	0.32	0.98	0.06	0.54	0.92	**0.56**	0.27	0.04
Fallow practised	0.08	0.40	0.06	0.18	1.27	0.89	**1.06**	0.47	0.03
Seed variety: improved	**0.84**	0.32	0.01	0.03	0.88	0.71	0.04	0.27	0.87
Fertiliser use	**1.54**	0.54	0.006	**1.62**	0.73	0.04	**1.17**	0.32	< 0.001
Manure use	0.23	0.34	0.50	0.85	0.66	0.21	**1.92**	0.31	< 0.001
Fertility level: moderate	1.14	0.82	0.17	0.45	1.32	0.74	0.19	0.36	0.59
Fertility level: fertile	1.19	0.94	0.21	0.02	1.53	0.99	0.47	0.42	0.26
Fertility level: very fertile	**2.59**	0.96	0.009	-	-	-	0.02	0.83	0.98

Dependent Variable: Maize grain yield (t ha^{-1})

Bold estimate values are significant at ≤ 5% probability level

S.E is the standard error of the mean

Table 5 Mixed-effects model parameters for the management factors associated with pigeonpea grain yield in Northern Tanzania during 2016/2017 main agricultural season

Independent variables	Estimate	S.E.	Sig.
Density at harvest (plants ha^{-1})	**0.00005**	0.00001	< 0.001
Years under cultivation (years)	− 0.004	0.005	0.41
Slope: flat	–	–	–
Slope: gentle	− 0.09	0.20	0.65
Distance from homestead (m)	− 0.0005	0.009	0.96
Weeding frequency (numbers)	0.28	0.21	0.20
Fallow practised	− 0.14	0.37	0.71
Seed variety: improved	− 0.05	0.25	0.84
Fertiliser use	0.03	0.20	0.88
Manure use	− 0.02	0.19	0.91
Fertility level: moderate	–	–	–
Fertility level: fertile	− 0.05	0.20	0.82
Fertility level: very fertile	− 0.02	0.26	0.42

Dependent Variable: Pigeonpea grain yield (t ha^{-1})

Bold estimate values are significant at ≤ 5% probability level

S.E is the standard error of the mean

16% higher yields when manure was applied compared with fields that received no manure. For fields with plant density higher than 24,000 plants ha^{-1} on flat and gentle slopes, fertiliser use increased yields by 28% (Fig. 5). In contrast to maize yields, only plant density at harvest was a significant factor in explaining pigeonpea yields (Table 4). Plots with higher plant density at harvest gave larger pigeonpea grain yield; fields with plant density above 24,000 plants ha^{-1} had an average of 1.4 t ha^{-1} while those with plant density less than 24,000 plants ha^{-1} yielded 0.5 t ha^{-1} on average.
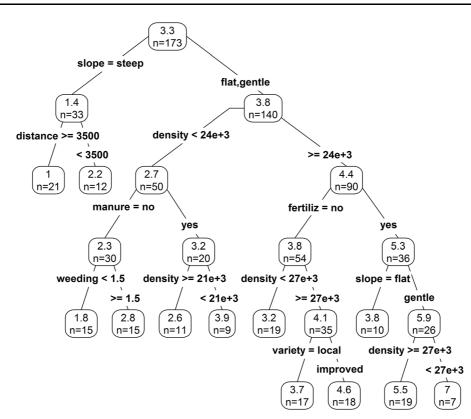
Fig. 5 Association of key management parameters with maize grain yield as observed from various farmer fields ($n = 173$) in Northern Tanzania. Enclosed is yield t ha^{-1}; n = number of farms. Considered factors: slope = slope of the field (steep, flat or gentle); distance = field distance from the homestead (m);

density = plant density at harvest (plants ha^{-1}); manure = manure use (yes or no); fertiliz = fertiliser use (yes or no); weeding = weeding frequency (numbers); variety = maize seed used (local or improved)Mean squared error (MSE) of the model = 3.55

Discussion

The majority of sampled farmers ($\geq 55\%$) planted seed of improved maize varieties mainly purchased from agro-dealers whereas for pigeonpea, a majority ($\geq 90\%$) relied on saved seeds. This is a common situation in Northern Tanzania where previous studies have reported that 79% of farmers used improved maize seed varieties (Kihara et al. 2015), whereas a majority relied on saved pigeonpea seeds (Silim et al. 2005). Intercropping was ubiquitous across all sampled fields in Northern Tanzania. The most common intercropping system was maize–pigeonpea which was practiced by more than 50% of the sampled farmers. Although far less frequent, maize was also intercropped with beans (25%), sunflower (11%) and other crop species (10%). Long-duration pigeonpea varieties were most common (data not shown), which are preferred due to their greater yield potential

(Shiferaw et al. 2007). In general, maize yielded more grain when intercropped with pigeonpea than when intercropped with other crop species. The slow initial growth of pigeonpea makes it well suited for intercropping as there is little competition with the primary maize crop (Silim et al. 2005). Even when sown simultaneously with maize, pigeonpea has a longer growth cycle and can continue to grow for up to three months after maize harvest (Myaka et al. 2006). With the extended period of growth, the greatest demand for water and nutrients in pigeonpea occurs after maize has been harvested (Dalal 1974). As such, pigeonpea does not affect the yield of the companion maize crop (Kimaro et al. 2009; Myaka et al. 2006). The greater maize yield when intercropped with pigeonpea was not significantly different from other intercrops (Fig. 3), probably due to the large difference in the number of observations (n) of the various intercrop systems, where the number of cases for maize–

pigeonpea intercrops was substantially larger. We attribute the popularity of maize–pigeonpea intercrops to their multiple benefits, among others the use of green pods for food, the good market for dry grain (Löfstrand 2005; Silim et al. 2005), and the stems remaining after harvest are used for fencing or as firewood (Adu-Gyamfi et al. 2007; Myaka et al. 2006).

Maize grain yields were significantly greater in the Kilimanjaro region than in Arusha and Manyara regions, while pigeonpea grain yield was comparable across regions (Fig. 4). This significantly greater yield in maize in the Kilimanjaro region was associated with the more fertile soils with larger soil C and N concentrations (Table 1), which are important indicators of soil quality. In relation to this, it is notable that 41% of the farmers sampled in Kilimanjaro used fertiliser as compared with only 10–11% in Arusha and Manyara (Table 2). Pigeonpea biomass at the time of maize harvest was 3.5 t ha^{-1} while biomass at physiological maturity was 3.4 t ha^{-1}. Pigeonpea grows for an extended period of three to four months after maize harvest by accessing sub-soil moisture due to its deeper rooting system (Mafongoya et al. 2006). The reduction in pigeonpea biomass observed in this study at the time of harvest is due to the fact that despite the longer growth period, pigeonpea plants shed large amounts of leaves as they approach maturity. The fallen pigeonpea leaves were not included in the samples for determining final aboveground biomass, which is known to lead to underestimates of overall biomass production for pigeonpea (Sheldrake and Narayanan 1979). This leaf litter can contribute greatly to soil fertility; 75–95 kg N ha^{-1} was added to the soil from senescent pigeonpea leaves in maize–pigeonpea intercrops in Malawi (Sakala 1998).

The most important factors associated with variability in yield were plant density at harvest, fertiliser use and slope, as these were significant across more than one region (Table 4). Other factors included manure use, years the land had been under cultivation, weeding frequency, seed variety used, fallow practice and fertility level. Yield variability is often attributed to heterogeneity and differences in landscapes and soils, and the corresponding agronomic and management practices (Njoroge et al. 2019; Tamene et al. 2016). There was wide variability of plant spacing and plant density, with a median value of 26,000 and 18,000 plants ha^{-1} for maize and pigeonpea

respectively. In our study, denser plant densities at harvest gave larger yields for both maize and pigeonpea, as observed elsewhere (Fanadzo et al. 2010). The wide variability in plant spacing and low plant densities at harvest is partly associated with the use of ox-drawn ploughs and the broadcasting of seeds leading to random arrangement of the crops. Each additional year that fields had been cultivated in Arusha led to a decrease in maize yields, suggesting decline in soil fertility as a cause especially given that only 10% of the farmers used fertiliser in the region. The reasons highlighted for not using fertiliser included lack of cash, low response rate and high prices. The sparse use of fertiliser has also been attributed to lack of information on its benefits and the absence of input suppliers (Adu-Gyamfi et al. 2007; Mowo et al. 2006). Additionally, Mapila et al. (2012) found that smallholder maize farmers in Southern Africa (Malawi, Mozambique and Zambia) did not use fertiliser due to a perception that it would have detrimental effects on their soils, and they attributed such perceptions to a lack of farmer training on fertilisers. The extra yield realized due to addition of fertiliser or manure (1.5 t ha^{-1} and 0.9 t ha^{-1} respectively) underscores the importance of replenishment of the nutrients removed through harvest of grains, maize stover for livestock feed and pigeonpea stems for fuelwood (Kihara et al. 2015). Indeed, manure has multiple benefits on soil fertility (Zingore et al. 2008) which explains its role in increasing yield. More frequent weeding had a positive effect on maize yields, where each additional weeding event resulted in 0.39 t ha^{-1} extra yield. Yields on fields that farmers rated as very fertile were 1.62 t ha^{-1} greater than infertile fields (Table 4), which is unsurprising given that crop yields were among the criteria used to rate the fertility of fields. Larger total carbon (C) and available P concentrations were also found in fields that farmers considered to be fertile (Table 3). Maize yielded poorly on steep slopes as compared to flat and gentle slopes and this was even exacerbated where the steep slopes were farther from the homestead; yields on more steep slopes that were closer to the homestead produced higher yields than those that were farther away (Fig. 5). This could be attributed to the fact that fields that are farther from the homestead are often located on steeper slopes and more prone to erosion risks (Giller et al. 2011; Mowo et al. 2006). Further,

fields that are farther from the homestead often receive less nutrient inputs (Zingore et al. 2008).

Conclusions

This study systematically illustrates current practices in maize – pigeonpea intercrops by combining agronomic, structural and socio-economic information in three regions of Northern Tanzania. We identify promising interventions to increase yields of intercrops. Improved soil fertility management using manure where it is available and supplementing with mineral fertilisers will enhance yields of the intercrops. Greater awareness through training farmers on balanced nutrition and fertiliser use is needed. The importance of optimising plant density and implementing soil conservation measures on steep slopes is also clear. The large amount of pigeonpea leaf fall which is left in the field after harvest can contribute greatly to soil fertility through nutrient cycling and maintenance of soil organic matter for long term sustainability. Residual benefits that the intercropped legume crops and in particular pigeonpea provide to the subsequent maize crop deserve more detailed investigation. Furthermore, since intercrops are known to increase aggregate yields per unit input through complementarity in utilization of nutrients, water and solar radiation, studies to assist in quantification of such benefits are strongly recommended.

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