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Evaluating oat cultivars for dairy forage production in the central Kenyan highlands

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With the projected increase in future demand for animal products, efforts to raise animal productivity are necessary to match the rise. Already, the estimated per-capita milk consumption in Kenya has increased to 150 L from 100 L estimated in 1998 while the population is growing at 2.65% annually. Improving milk production is largely constrained by inadequate feeding, particularly from basal roughages. To contribute towards addressing this concern, five oat cultivars (Conway, Glamis, Balado, Mascani and Rhapsody) new to eastern Africa were evaluated versus a 'Local' check. Agronomic attributes, forage quality and farmers' preferences were assessed in the 2015/16 growing season. Dry matter (DM) yields ranged from 5 to 22 t DM ha^{-1} with Conway accumulating most DM, whereas the relative feed value was in the order Balado > Mascani > Rhapsody > Conway > Glamis > Local. However, crude protein (CP) yield (kg CP ha^{-1}) was highest in Conway and lowest in Mascani. The two most preferred cultivars by the farmers were Conway and Glamis. Based on DM and CP production, and farmers' choice, we conclude that Conway and Glamis stand a high chance of improving forage production in the area and other similar systems.

Keywords: agronomy, *Avena sativa*, forage quality, livestock production, smallholder, tropical highlands

Introduction

Inadequate year-round fodder availability constrains dairy production in many smallholder production systems of eastern Africa, including Kenya (Lukuyu et al. 2011). In Kenya alone, there are an estimated 1.8 m smallholder farmers (ILRI 2006), who produce about 80% of the marketed milk. Feeding accounts for 55–70% of the costs in a smallholder dairy (Odero-Waitituh 2017). Lack of enough fodder of adequate quality is attributable to several limitations, including small land holdings, limited knowledge and skills, unavailability of seeds and planting materials, and poor targeting of forages. For example, Napier grass (*Pennisetum purpureum* Schumach.), despite being the most adopted fodder in Kenya (Staal et al. 1998), performs poorly in cold areas, particularly at altitudes above 2000 m above sea level (asl) (Boonman 1993), which are characterised by low temperatures and occasional frosts (Jaetzold et al. 2006). However, farmers in the highlands continue growing Napier grass despite the long time it takes to attain a harvestable stage. In the same highland area, other forages relied upon, although to a lesser extent, include unimproved natural pastures, oats (*Avena sativa* L.) and sorghum (*Sorghum bicolor* (L.) Moench) (Lukuyu et al. 2011; Muia et al. 2011; Mwendia et al. 2015). Except for oats, the other tropical grasses grown do not perform well under these temperate conditions. Furthermore, the oats grown often constitute unidentified or unimproved cultivars, coupled with limited cultivar choices. In addition, little testing of different fodder oat cultivars has taken place in Kenya.

Fodder oats have been successfully used elsewhere, especially in temperate environments including tropical highlands (e.g. Rahetlah et al. 2010; Salgado et al. 2013; Beyene et al. 2015), to provide the basal diet for livestock. The worldwide trend has been to encourage oat use for fodder in smallholder production systems (Suttie and Reynolds 2004), which has thus increased over the last 20 years, probably also due to its versatility. Oats can be grazed, cut and carried, and conserved as either hay or silage (Suttie and Reynolds 2004). In eastern Africa, however, the area under fodder oats has greatly decreased after independence. For example, in Kenya oat cultivation for fodder declined by over 50%, from >11 000 ha to 5 000 ha in the period 1960–1970, partly because of changing farming systems and land-holding sizes (Suttie and Reynolds 2004). The area under oats in Kenya has remained at this low level (4 000 ha in 2012 according to FAOSTAT 2013). In the region, there is only Ethiopia with an appreciable area under oats that has increased lately (Suttie and Reynolds 2004; Beyene et al. 2015). Despite the current situation in Kenya, there is increased interest in livestock and, especially, the dairy sector with the projected doubling of livestock products, milk included, by 2050 (Sattari et al. 2016). Elsewhere, such as in the tropical highlands of the Andes, use of oats for fodder or soil

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cover is popular covering an estimated 3 million ha (Suttie and Reynolds 2004). Due to the adaptability of oats to a wide range of altitudes in the tropics (i.e. 1 750–3 000 m) according to Boonman (1993), this grass could be an important source of quality fodder provision (Marshall et al. 2013). Apart from cultivars available in the early 1960s in eastern Africa, namely 'Suregrain', 'Lampton' and 'Grey Algerian' (Boonman 1993), there has been little effort to evaluate and promote high-yielding forage oats over the years, outside Ethiopia (Feyissa et al. 2007; Beyene et al. 2015) and lately in Madagascar (Rahetlah et al. 2010). This work, therefore, aimed to introduce and evaluate oat cultivars bred at Aberystwyth University, UK for grain production, for their fodder suitability as well as acceptability in smallholder dairy systems in the Kenyan highlands.

Materials and methods

Site description and experimental design

On-farm trials were conducted at Ol Joro Orok in Nyandarua county of Central Kenya from May to September 2015 in the first wet season, and repeated from October 2015 to January 2016 in the second season. A participatory approach was used involving three organised dairy farmer groups, namely Nyamarura, Hillten and Kanguu. Discussions with the groups led to selection of two farms in each of Nyamarura and Kanguu, and one farm of Hillten for conducting the trials. Details of the soils in the specific trial sites are given in Table 1. Soil analysis was undertaken at the CIAT laboratory based on five soil samples per farm collected at about 20 cm depth with a soil auger. Soils were slightly acidic clays or clay loams with medium to low contents of nitrogen (N) and phosphorus (P), with particularly low fertility at the Kanguu farms.

The geographic locations and altitudes of the sites were, respectively, 00°09′ S, 36°18′ E, and elevation 2 667 m asl (Farm 1); 00°09′ S, 36°17′ E, and 2 808 m (Farm 2); 00°08′ S, 36°20′ E, and 2 546 m (Farm 3); 00°03′ S, 36°24′ E, and 2 359 m (Farm 4); and 00°03′ S, 36°24′ E, and 2 368 m (Farm 5). In the second season, the trial was repeated on Farm 2 only, because too little seed was available for planting on more farms after the first season. Unfortunately, the lack of an orthogonal design hampered data interpretation. Key weather variables during the trial period are summarised in Figure 1. The weather was generally normal except for unusually high rainfall during November and December, 2015. Energy input in growing degree days (GDD; in °Cd) was established according to McMaster and Wilhelm (1997) as GDD = Σ(mean daily temperature − 5 °C). The first season (13 May 2015–4 September 2015) had a net energy input of 1 127 °Cd, 52 rainy days and 295.3 mm rainfall. For the second season (28 October 2015–31 January 2016), the same values were 1 023 °Cd, 54 rainy days and 389.8 mm, respectively.

The five tested forage oat cultivars were the winter oats 'Balado', 'Mascani' and 'Rhapsody', and spring oat 'Conway' and 'Glamis'. These cultivars were bred by the Institute of Biological, Environmental and Rural Sciences (IBERS) for grain production and released in the UK by the Agriculture and Horticulture Development Board, a registered trademark (HGCA 2014, 2015). Release happens after two years of testing of distinctiveness, uniformity and stability before cultivars are added to the National List (NL). After a further two years of testing on grain yield and quality, they can be added to the Recommended List (RL) (Table 2).

Currently, no category for forage or multipurpose oats exists in the UK. The two spring and three winter oat cultivars were included to be tested in Kenya for forage production. Spring oats were chosen for their rapid growth as being suitable for forage production; here we selected the most recent lines from the breeding program for testing, Conway and Glamis. Mascani, on the other hand, is the most widely grown winter oat cultivar in the UK due to its excellent grain quality characteristics; it was also selected on the basis of biomass yield when spring-sown. The reason that Balado was included, being a dwarf oat, was high grain yield and considerable biomass production with a large flag leaf. Rhapsody was included as it is the highest-yielding grain cultivar available in the UK (AH Marshall, Institute of Biological, Environmental and Rural Sciences, Aberystwyth University, UK, pers. comm.).

These 'new' cultivars were tested against a local check referred to as 'Local' for the purpose of this study; the seeds of this unnamed local cultivar for both seasons were bought at the same time from an agricultural input shop in Nyahururu town. The trials were laid out in a completely randomised block design with three replicates of each cultivar in each of the five farms.

Trial establishment and maintenance

The farmer groups prepared seedbeds manually with hoes, breaking soil clods to obtain a fine soil tilth. Plot sizes of 6 m^2 (3 m length × 2 m width) were marked out using wooden pegs. Furrows at a distance of 15 cm between rows of about 6 mm depth were made in each plot. Inorganic MEA fertiliser® (NPK fertiliser 23:23:0) was applied at the rate of 50 kg N ha^{-1}. Oat cultivars were randomly allocated to plots within each replicate. During 12–14 May 2015 for the first season, and on 28 October 2015 in the second

Table 1: Soil properties (0–20 cm depth) at on-farm oat trial sites in Ol Joro Orok, Nyandarua county, central Kenya (source: International Center for Tropical Agriculture (CIAT) Laboratory, Duduville, Nairobi). N = nitrogen, C = carbon, P = phosphorus

Farmer group	*n*	Clay (%)	Sand (%)	Silt (%)	Soil type	pH	Total N (%)	Total C (%)	Bray P (mg kg^{-1})
Nyamarura (Farm 1)	5	34.8	31.9	33.3	Clay loam	5.0	0.32	3.6	16.2
Nyamarura (Farm 2)	5	37.5	34.5	28	Clay loam	5.6	0.27	2.9	12.9
Hillten (Farm 3)	5	43.2	31.2	25.5	Clay	6.1	0.35	3.7	8.6
Kanguu (Farm 4)	5	42.1	35.9	22	Clay	5.2	0.19	2.1	8.3
Kanguu (Farm 5)	5	47.7	34.3	18	Clay	5.4	0.18	2.1	2.6

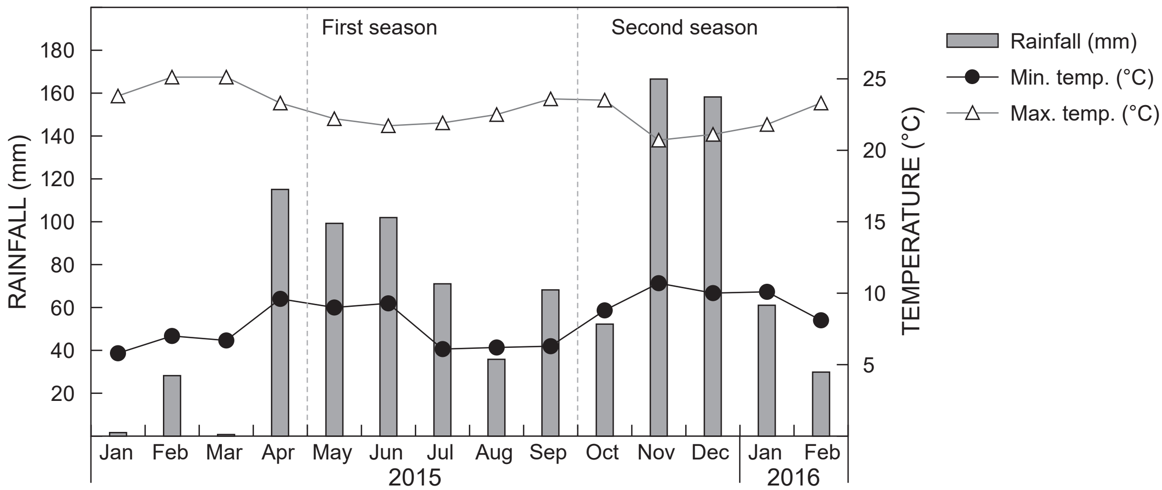

Figure 1: Monthly rainfall (mm), and mean minimum and maximum temperatures (°C) in 2015 and early 2016 covering the trial periods. Data sourced from Kenya Agricultural and Livestock Research Organization (KALRO)–Ol Joro Orok

season, seeds were spread along the furrows at the rate of 100 kg ha^{-1} and shallowly covered with soil.

Measurements

Seedlings, tillering and plant height

At three and six weeks after sowing, seedlings and tillers (Assefa and Ledin 2001) were counted in a quadrat of 0.25 m^2 per plot, positioned by placing a quadrat (50 cm × 50 cm) more or less at the centre of the plot. Plant height (cm) was measured from the base of a tiller to the highest standing point on four randomly selected plants per plot, just before harvesting.

Dry matter yield

Herbage yields were assessed at the dough stage attained at about 115 d of growth in the first season and at the boot stage (95 d of growth) during the second season. The earlier harvesting date in the second season was motivated by signs of leaf rust that started to appear, whereas in the first season no such symptoms were noticed. The herbage within a quadrat of 1 m^2 was harvested from the centre of each plot, and fresh weight determined using a digital weighing balance (Hanging Scale CH50K100, Kern and Sohn, Balingen, Germany). A sample of approximately 200 g was randomly selected from the harvested herbage of each plot and the fresh weight was recorded. The samples were then oven-dried to constant weight at 65 °C for 48 h and weighed to determine the dry matter (DM) content. Only samples, from the first season and each plot from the five farms, were further ground to pass through a 1 mm sieve and stored in sample bottles for subsequent nutritional analysis.

Forage quality

Crude protein (CP) was determined by analysing N by the combustion method at 900 °C with a vario MAX Cube elemental analyser (Elementar, Hanau, Germany). Nitrogen values were then multiplied by a factor of 6.25 to derive CP contents. Acid detergent fibre (ADF) and neutral detergent fibre (NDF) were estimated by the Ankom bag technique with an ANKOM 143 fibre analyser (ANKOM Technology, Fairport, NY, USA) following the AOAC procedure (AOAC 1975) at the CIAT laboratory in Nairobi, Kenya.

Table 2: Description of oat cultivars included in evaluation. RL = Recommended List, NL = National List

Cultivar	Type	Release year
Conway	Spring	2014 RL
Glamis	Spring	2013 NL
Mascani	Winter	2004 RL
Balado	Winter	2010 RL
Rhapsody	Winter	2014 RL

The ADF and NDF values were used to estimate digestible dry matter (DDM) and dry matter intake (DMI) relative to body weight. Subsequently, relative feed value (RFV) was calculated using the formulae in accordance with Jeranyama and Garcia (2004) as: DDM = 88.9 – (0.779 × %ADF), DMI = 120/(%NDF), and RFV = (DDM × DMI)/1.29. Crude protein was used to estimate CP yield (kg CP ha^{-1}).

Participatory evaluation

At three months after planting, farmer groups in their respective trial sites and during the first wet season, were guided in conducting a participatory evaluation. The farmers developed forage evaluation criteria of their own and scored them on a scale of 1 to 10, where 1 represented least and 10 most important. The criteria were further used to score against each of the oat entries, again on a 1 to 10 scale.

Statistical analyses

Data were managed in Microsoft Excel and analysed with GenStat 14th Edition software (VSN International, Hemel Hempstead, UK, 2011). Except for the participatory scores, data were first subjected to a Shapiro–Wilk normality test. One-way analysis of variance (ANOVA) in randomised blocks was executed for each season, including analysis of contrasts. In the model, measured variables were fitted as a *y*-variate and factors as cultivar, season and farm. Effect of season was analysed for Farm 2, for which data on both seasons were collected, and farm effects were analysed for the first season. Contrasts were run for Local versus spring oats, Local versus winter oats, and Local versus spring and winter oats combined, across growth attributes measured. The least significant difference (LSD) was used to separate means for quality attributes. Standard error of the mean (SEM) was used to separate means presented in bar charts for number of seedlings, number of tillers, DM yield, DM content and plant height. It was calculated as SEM = $\sigma/\sqrt{n}$, where σ = standard deviation and n = number of observations. The participatory scores were weighted in accordance with Abeyasekere (2001) by the formula:

$$\mathrm{WS} = \frac{\sum\left(C_1V_1 + \cdots + C_nV_1\right)}{C_1 + \cdots + C_n}$$

where WS = weighted score, C = score on criteria, and V = score on cultivar. Correlations (r) between weighted score, averaged for the three farmers' groups, and some selected growth attributes were analysed with GenStat 14th Edition.

Results

Agronomic performance

Seedlings and tillering among the oat cultivars varied at three and six weeks of growth, respectively, and between the seasons (Figure 2a–d). At three weeks of growth, the number of seedlings ranged from about 150 to 325 (first season–all farms). Tiller numbers were high at six weeks of growth, ranging from 500 to 700 for all farms and 550 to 950 in the second season on Farm 2. At three weeks of age, the number of seedlings was largely in the order of Glamis > Conway > Local > Balado > Rhapsody > Mascani, and the same in the second season on Farm 2 except for the interchange of Balado and Rhapsody. At six weeks in the first season (all farms), the order among the cultivars had changed to Conway > Balado > Glamis > Local ≈ Mascani ≈ Rhapsody. This contrasted with the second season on Farm 2: Rhapsody > Conway > Balado > Local > Glamis > Mascani (Figure 2c and d).

When comparing the seasons, the oat cultivars consistently maintained the same order of plant height (Figure 2e and f). Cultivars sorted in decreasing order of height were Conway > Glamis > Local > Rhapsody > Mascani > Balado. In either of the seasons, only Conway and Glamis attained heights >1 m. Generally, DM content was higher in the first season than in the second (Figure 2g and h) because of the later maturity stage (dough vs boot stage) at harvesting of the former. The Local cultivar had substantially higher DM content than the remainder of the cultivars, whereas spring cultivars were higher in DM content than winter cultivars in the first season (Figure 2g and h). In the second season, there were no significant differences in DM content among all cultivars (Figure 2h). In both of the seasons, Conway accumulated the highest DM yield (t ha^{-1}), which was significantly higher than all cultivars in the first season but similar to that of Glamis in the second season (Figure 2i and j).

Contrast comparisons

Significant contrasts during both first and second seasons were identified between Local and spring oats (Conway and Glamis) for plant height only, whereas between Local and winter oats (Balado, Mascani and Rhapsody) contrasts were significant for number of seedlings at three weeks and plant height (Table 3). However, when contrasted for all oats versus Local, it was only significant for DM content and yield (first season) and the number of seedlings at week 3 in the second season. For every unit increase in plant height by Local (first season), spring oats would increase by 0.83, whereas DM content would decrease by 0.183. However, in the second season, there was an increase by 0.51 units in plant height for spring oats, for every unit increase of plant height in Local, whereas DM was not affected. Winter oats compared with Local had significantly lower plant height, DM content and DM yield for every unit increase for Local in the first season, and a similar state of attributes in the second season was observed although not significant for DM content and yield.

Farm differences

Farm by cultivar differences were significant for number of seedlings and tillers, plant height, DM yield and DM content (Figure 3).

Forage quality

Measured quality parameters (first season only) revealed cultivar differences (Table 4). The CP content was relatively high in winter oats compared with either Local or spring oats. However, spring oats and Local produced higher CP yields (kg ha^{-1}). The fibre (ADF and NDF) contents were higher in Local and spring oats compared with the winter oats, whereas Local had the least estimated DDM and DMI. Across the farms, the quality attributes differed with relative feed value (RFV) being least on Farm 5 and CP yield was least on Farm 4, both of which had relatively poor soils (Table 4).

Participatory evaluation

Farmers' participatory evaluation criteria differed slightly among the groups but largely entailed attributes that are related to herbage production and what farmers perceived to be important in their location, such as disease tolerance in Kanguu and weed suppression in Hillten (Table 5). Criteria ranged from perceived herbage accumulated, plant height, tillering, broad leaves and existence of silica hairs, to the associated benefit of weed suppression. There were seven criteria in Kanguu, eight in Nyamarura and nine in Hillten. Across farmer groups, the first three ranked cultivars were Conway > Glamis > Local. The other three cultivars (Rhapsody, Mascani and Balado) differed among the groups, with Mascani the lowest rated by the Kanguu and Hillten groups, as was Balado and Mascani by Nyamarura farmers (Table 5). The Local cultivar used in both seasons represented what the farmers are familiar with in the region, normally accessed from agro-shops in the area.

Correlation of attributes

Pooled weighted scores showed strong correlation (r) with measured growth attributes and biomass production (Table 6a). The farmers' perception and rating of the criteria most relevant to them mirrored the agronomic performance

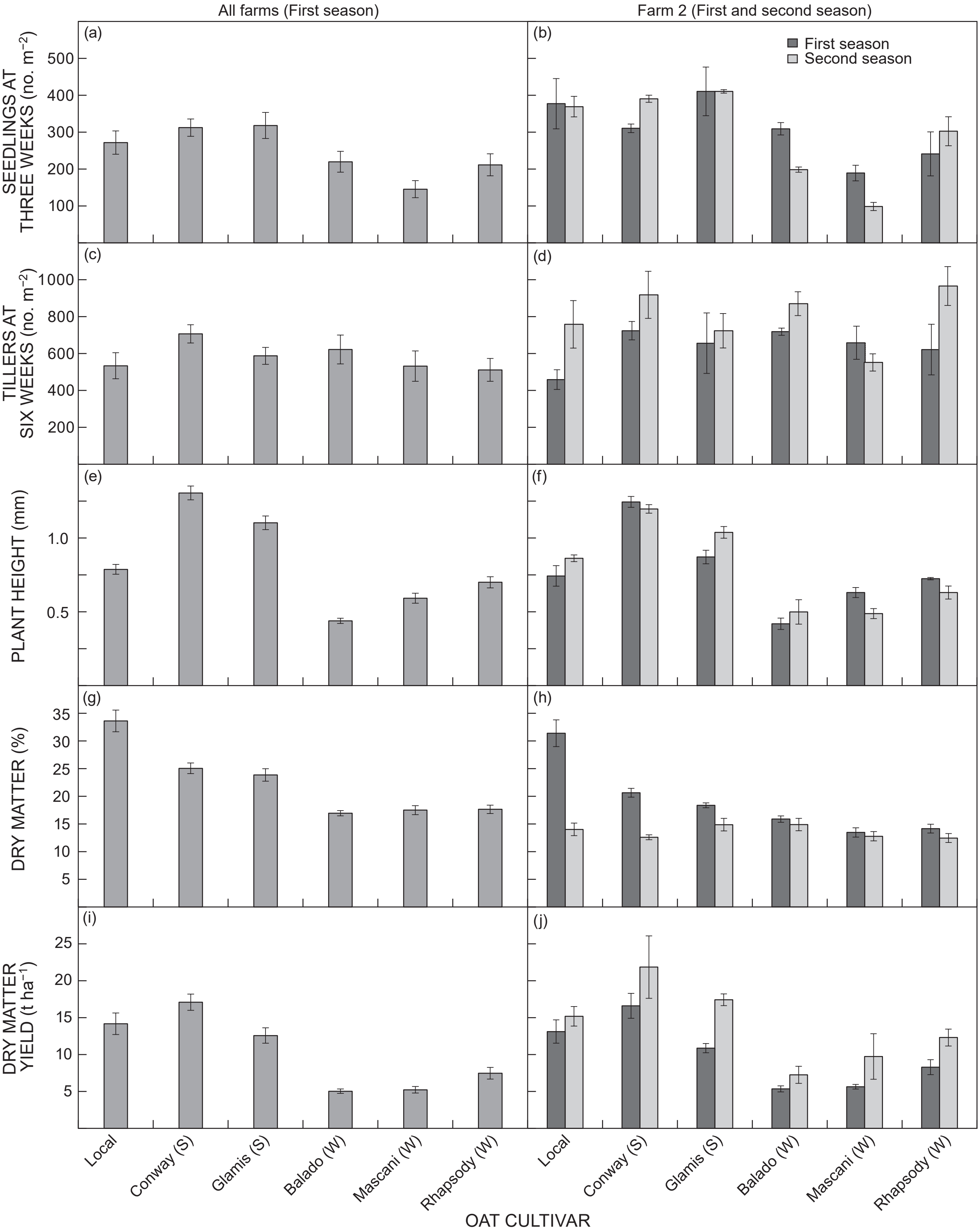

Figure 2: Mean performance of spring (S) and winter (W) oat cultivars in terms of seedlings (a and b), tillering (c and d), plant height (e and f), dry matter (g and h) and herbage yield (i and j) during the first rain season in all farms (a, c, e, g and i) and in Farm 2 in the first and second wet seasons (b, d, f, h and j) in Ol Joro Orok, Nyandarua county, central Kenya in 2015/16. Error bars represent the SE

Table 3: Contrast comparisons between Local and spring and/or winter oat cultivars during the first and second growth seasons at Ol Joro Orok, Nyandarua county, central Kenya in 2015/16. Values in parentheses denote the SE

Attribute	Local versus spring oats	Local versus winter oats	Local versus spring and winter oats
First season (all farms)			
No. of seedlings at three weeks	22 (17.8)^{ns}	−60 (25.2)*	−38 (39.8)^{ns}
No. of tillers at six weeks	57 (40.6)^{ns}	16 (57.5)^{ns}	73 (90.8)^{ns}
Plant height (m)	0.83 (0.091)***	−0.63 (0.129)***	0.20 (0.024)^{ns}
Dry matter content (%)	−0.183 (0.027)***	−0.488 (0.038)***	−0.671 (0.061)***
Dry matter yield (t ha^{-1})	1.3 (2.34)^{ns}	−24.8 (3.30) ***	−23.5 (5.22)***
Second season (Farm 2)			
No. of seedlings at three weeks	63 (47.8)^{ns}	−508 (75.6)***	−445 (106.9)**
No. of tillers at six weeks	125 (218)^{ns}	113 (308.4)^{ns}	239 (487.6)^{ns}
Plant height (m)	0.51 (0.111)***	−0.97 (0.157)***	−0.46 (0.249)^{ns}
Dry matter content (%)	−0.006 (0.0192)^{ns}	−0.019 (0.0271)^{ns}	−0.025 (0.0429)^{ns}
Dry matter yield (t ha^{-1})	8.9 (5.50)^{ns}	−16.3 (7.78)^{ns}	−7 (12.3)^{ns}

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, ns = not significant

Table 4: Forage quality of spring (S) and winter (W) oat cultivars during the first wet season in Ol Joro Orok, Nyandarua county, central Kenya in 2015. ADF = acid detergent fibre, NDF = neutral detergent fibre, DDM = digestible dry matter, DMI = dry matter intake, RFV = relative feed value, CP = crude protein

Oat cultivar/Farm	CP (%)	ADF (%)	NDF (%)	DDM (%)	DMI (%)	RFV (%)	CP yield (kg ha^{-1})
Cultivar							
Local	8.0	44.8	63.4	54.0	1.91	80.0	1 054
Conway (S)	7.0	42.1	59.1	56.1	2.05	89.3	1 137
Glamis (S)	8.5	40.6	62.2	57.3	1.95	86.7	1 007
Balado (W)	15.5	27.8	44.7	67.3	2.73	142.5	765
Mascani (W)	13.3	30.3	48.9	65.3	2.49	126.9	664
Rhapsody (W)	13.6	31.7	50.5	64.2	2.42	121.2	950
LSD ($p = 0.05$)	1.32***	3.2***	12.7***	2.49***	0.20***	12.7***	88.7***
Farm							
1	11.3	37.1	53.5	60.0	2.30	108.3	1 013
2	8.8	34.9	52.6	61.7	2.34	113.3	1 039
3	10.9	38.9	53.0	58.6	2.36	109.8	948
4	14.9	32.3	53.4	63.7	2.31	115.1	789
5	9.1	37.8	61.5	59.5	1.98	92.3	857
LSD ($p = 0.05$)	2.52***	5.09*	5.97*	3.97*	0.26*	19.1*	203.4*

* $p < 0.05$, *** $p < 0.001$

of the oat cultivars. Plant height and number of seedlings at three weeks showed the highest positive correlations with DM yield across farms for the first season. Similarly, the same correlation was strongest for Farm 2 in either the first or second season (Table 6b and c).

Discussion

Performance of oat cultivars

Herbage performance was superior in Conway (Figure 2i and j), which produced >16% more biomass than Glamis, the second best performing cultivar. The high growth rate that characterised the tall plants of Conway (Figure 2e and f) must have contributed to the high biomass achieved in both seasons. Although the Local check, especially during the first season, had much higher DM content, its short plants vitiated this advantage, resulting in lower herbage yield compared with that of Conway, but similar to that of Glamis. The relatively large number of tillers in Conway (Figure 2c and d) also contributed to the observed high biomass production. Usually, plant height and tillering are both positively correlated with biomass accumulation (Shah et al. 2015; Mwendia et al. 2016), an observation that was also made in the present study (Table 6), and appeared inherent in Conway. Although in the UK the cultivars are measured for grain and not forage production, only the two spring oats (Conway and Glamis) attained a similar height (>1 m) in Kenya also observed in their straws in the UK (HGCA 2014, 2015). In contrast, the winter oats (Mascani, Rhapsody and Balado) reached much lower heights (0.5–0.75 m) than those attained in the UK (0.86–1.09 m).

The forage yields obtained across the cultivars (5–22 t DM ha^{-1} cut^{-1}) were broadly comparable to those reported in other studies (3–10.8 t DM ha^{-1} cut^{-1} and 11.5–23.1 t DM ha^{-1} cut^{-1}) in Korea and Pakistan, respectively (Kim et al. 2006; Bilal et al. 2017). Despite the first season extending for 20 d longer than the second season, it is noticeable that herbage yield was higher in the second season than in the first. The comparable energy input in growing degree days (GDD) of the two periods cannot explain this; however, the second season apparently benefited from substantially

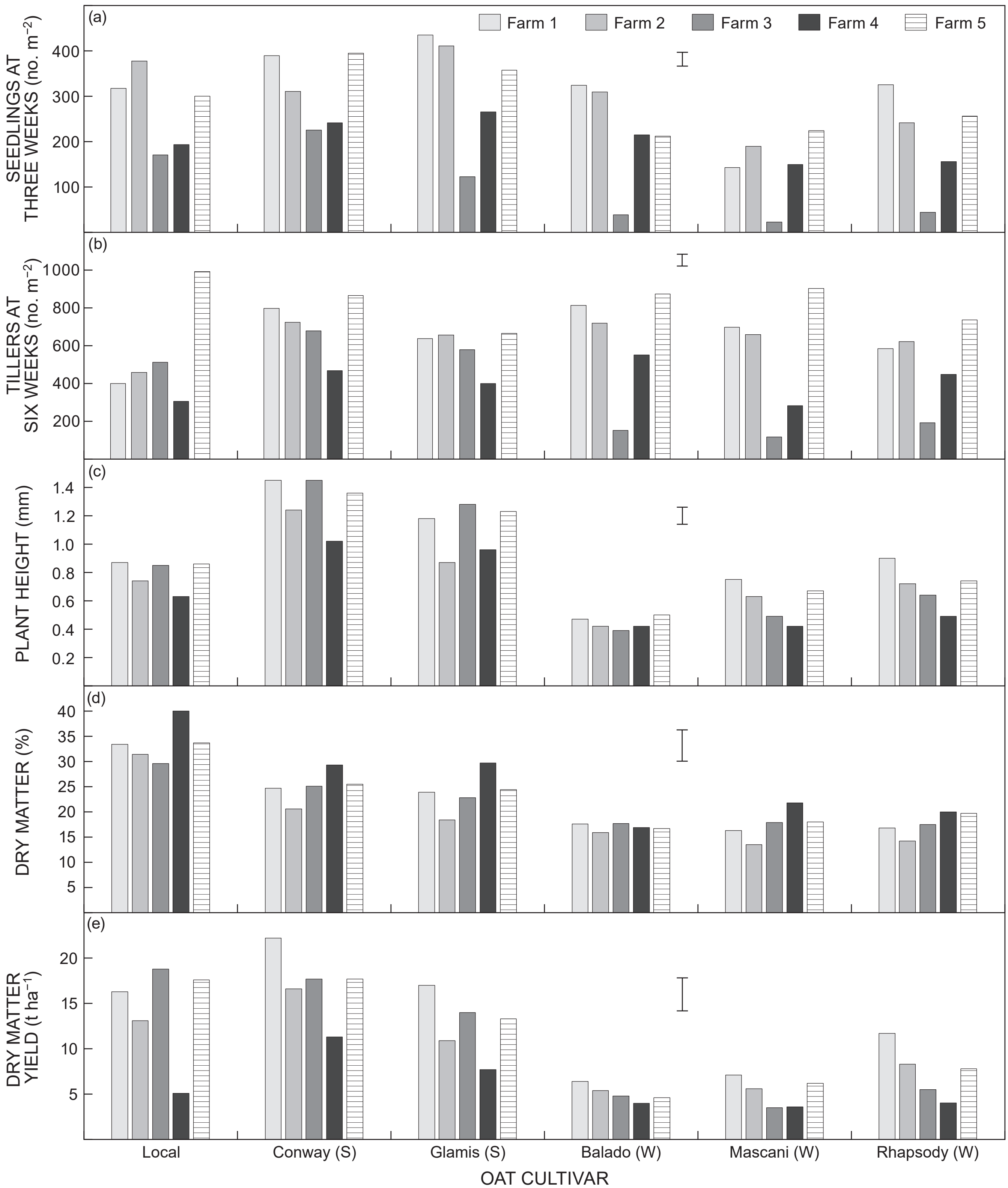

Figure 3: Farm by spring (S) and winter (W) oat cultivar effects on number of seedlings at three weeks and tillers at six weeks (a and b), plant height and dry matter percentage at harvest (c and d) and herbage yield (e) during the first wet season in Ol Joro Orok, Nyandarua county, central Kenya in 2015. The bar in each chart represents the least significant difference among the means

Table 5: Participatory evaluation of spring (S) and winter (W) oats (scores from 1 to 10 and weighted scores) by Nyamarura, Kanguu and Hillten dairy farmer groups in Ol Joro Orok, Nyandarua county, central Kenya during the first season in 2015

Farmer group	Farmers' criteria	Criteria score	Oat cultivar (scores)					
			Local	Conway (S)	Glamis (S)	Balado (W)	Mascani (W)	Rhapsody (W)
Nyamarura	Growth rate	10	6	9	5	2	3	3
	High biomass	10	7	8	7	4	3	3
	High plant height	8	7	9	6	3	3	3
	High tillering	8	8	9	8	9	8	9
	Broad leaves	6	5	10	9	7	5	7
	Lodging	7	10	10	10	10	10	10
	Frost resistance	6	10	10	10	10	10	10
	Disease tolerance	5	7	9	8	3	7	7
	Weighted score		7.4	9.2	7.6	5.7	5.7	6.1
Kanguu	Growth rate	10	7	9	8	3	3	5
	High biomass	10	8	10	10	5	3	4
	High plant height	7	8	10	9	3	4	5
	Thick stem	7	8	9	9	3	3	4
	Broad leaves	8	8	9	9	3	3	4
	Weed suppressing	8	8	9	9	8	5	7
	Disease tolerance	10	7	8	8	3	4	5
	Weighted score		7. 7	9.1	8.8	4.0	3.6	4.9
Hillten	Germination rate	9	6	9	8	6	4	4
	Growth rate	8	6	10	9	4	2	3
	Biomass	10	6	10	8	2	1	2
	High plant height	7	8	10	9	3	3	4
	High tillering	8	7	9	8	10	10	9
	Silica hairs	3	10	10	10	10	10	10
	Lodging	5	10	10	10	10	10	10
	Weed suppressing	10	6	10	8	5	4	5
	Disease and pest tolerance	5	7	8	8	7	9	9
	Weighted score		6.9	9.6	8.5	5.7	5.1	5.5

(almost 100 mm) more rainfall than the first. This must have triggered the higher tillering of the cultivars in the second season compared with the first on Farm 2 (Figure 2d), which was up to 55% higher in Rhapsody. In the first season data (Table 6), there was a trend for higher DM yield as tillering increased. In addition, second-season plants were slightly taller in some cultivars than during the first season (Figure 2f). In this regard, plant height was strongly correlated with biomass accumulation ($r = 0.891$) in the first season, supporting also the higher second-season yield. The DM content was not higher in all cultivars in the first season compared with the second. Only the spring oat and Local cultivars had higher DM content in the first season, whereas winter oat cultivars maintained similar levels (Figure 2h).

Choice of cultivar had a considerable influence on the findings. For example, under contrast comparisons (Table 3), for every unit increase in forage biomass for the Local check, the other five cultivars combined had lower yields, especially in the first season. Similarly, winter oats had lower production when compared with the Local check, which was only comparable to spring oats. Conversely, the Local check was comparatively poor in quality attributes compared with winter oats (Table 4), but produced higher CP yield. Shah et al. (2015) also observed differences among eight oat cultivars evaluated for fodder yield in Pakistan. Nevertheless, it should be borne in mind that growth conditions, including management, could lead to differences in performance just as observed among the five farms, which also showed interactions with the cultivars (Figure 3).

Potential of the oat cultivars in dairy production

Considering that a mature cow consumes a daily DM equivalent of about 3% of its body weight (Wheeler 1996), the biomass gap between Conway and the Local check, equivalent to 2.9 t DM in the first season for example, is capable of providing feed for an additional seven months for a cow of about 450 kg live weight.

Although oats are regarded as an annual grass, they are capable of some regrowth, especially when grazed or harvested at the boot stage. However, the regrowth productivity is usually lower than that of the first crop (Boonman 1993), but given that regrowth occurs without re-establishment costs it would be beneficial. In cattle production systems that are intensifying and where grazing land is diminishing, such as in the present study area (Mwendia et al. 2015), increased forage output per unit area of land becomes critical to contribute to feed supply as this can account for between 60% and 70% of the costs in dairy farming (Madubuike 1993). However, forage quality is an important consideration in livestock productivity, especially in dairy farming. Forage quality can be influenced by many factors, including species and cultivar choice, but it also strongly depends on maturity at harvest.

Forage quality was quite variable among the oat cultivars (Table 4). All winter oat cultivars (Rhapsody, Mascani and Balado) with low fibre attained high RFV in addition to high CP contents. However, these cultivars accumulated significantly lower herbage resulting in overall lower CP yields per unit area of land. This reflects the importance of the

Table 6: Correlation coefficients (r) of pooled farmers' weighted scores and assessed agronomic oat attributes during (a) the first season across five farms ($n = 42$), (b) on Farm 2 in the first season ($n = 30$) and (c) Farm 2 in the second season of 2015 ($n = 30$) at Oljoro Orok, Nyandarua County, central Kenya. DM = dry matter, CP = crude protein

Attribute	Seedlings at week 3	Tillers at week 6	Plant height	DM %	DM yield	CP yield
(a) First season across five farms						
Tillers at week 6	0.564*					
Plant height	0.818**	0.571*				
DM %	0.233	0.682**	−0.067			
DM yield	0.866***	0.494*	0.891***	−0.125		
CP yield	0.878***	0.386	0.817**	−0.111	0.927***	
Weighted score	0.931***	0.632*	0.958***	0.071	0.950***	0.876***
(b) First season on Farm 2						
Tillers at week 6	0.455					
Plant height	0.877***	0.242				
DM %	0.159	−0.146	−0.003			
DM yield	0.827***	0.229	0.977***	−0.208		
(c) Second season on Farm 2						
Tillers at week 6	0.566*					
Plant height	0.683***	0.565**				
DM %	0.536*	0.040	0.269			
DM yield	0.814***	0.513*	0.895***	0.653**		

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

agricultural context within which agricultural technology is targeted. Possibly, these cultivars, if they can withstand grazing, could fit better under extensive systems, where the short height would not be prone to much trampling that would otherwise lead to wastage. Estimated digestible DM across the cultivars could lead to digestible biomass weights (t ha^{-1}) of 9.6 (Conway), 7.2 (Glamis), 7.6 (Local), 3.4 (Mascani), 4.8 (Rhapsody) and 3.4 (Balado). Clearly, the cultivars with higher biomass accumulation presented more digestible dry matter in addition to more crude protein accumulated per unit land area, making Conway a sensible choice being 20% higher than the Local check in this regard, whereas Glamis was only 5% lower than the Local check. Although the effect of feeding the oat herbage to animals was not attempted in this study, other studies have shown improved animal performance in terms of weight gain and milk production (Assefa and Ledin 2001; Mpairwe et al. 2003; Salgado et al. 2013). Milk production could be further increased by intercropping oats with legumes, such as vetch or faba bean (*Vicia* spp.), which would improve herbage quality as shown by Assefa and Ledin (2001) and Mpairwe et al. (2003). However, farmers' perspectives have the potential to influence the adoption of the lines to realise any impact.

Participatory scores (Table 5) across the farmer groups had Conway and Glamis ranked highest, remarkably matching the agronomic growth attributes measured. This was consistent with the most outstanding cultivar assessed by both agronomic characteristics and farmer participatory evaluation in northern Ethiopia (Alemu and Amare 2016). It is noteworthy that plant heights >1 m achieved by Conway and Glamis would make handling, especially at harvest, easier under a cut-and-carry system. Indeed, one of the key attributes considered during forage breeding is the agricultural context in addition to species and environment (Casler and van Santen 2010). This is underlined in this case by the fact that the farmers were able to present their own opinions by weighing the scores in favour of Conway and Glamis. Although forage quality of samples for either of the two spring oat cultivars as well as the Local check was lower than for the other cultivars, this was compensated by high herbage yield, leading to high values of DDM and CP yield, rendering them cultivars of choice for the farmers.

Future prospects of oats in the Kenyan highlands

Despite the fact that the 'new' cultivars tested here were bred elsewhere, they proved to perform well compared with the 'Local' cultivar. This suggests the lines provide good alternatives. Developing dairy farming in the Kenyan highlands, therefore, could benefit from even better oat cultivars that may have been developed elsewhere; for example, in Ethiopia (Feyissa et al. 2007), India (Ahmad et al. 2013), Argentina (Beratto and Rivas 2003a, 2003b) and some other countries, where oats continue to play a role as a forage. The starting point would still be to validate a broad set of cultivars under the intended conditions (Stevens et al. 2004). Developing fodder oat worldwide has generally received scant attention, especially in breeding (Stevens et al. 2004). Against this background, using the well-performing cultivars of the present study bred in the UK could be beneficial. A push by agricultural research and extension locally could bolster adoption of cultivars by farmers, and further evaluation in different areas should be considered, e.g. soils and other conditions in the highlands. However, seed production and distribution systems for adopted lines would need to be developed and, most likely, need to be sustainable under private-sector seed dealers.

Conclusion and recommendations

Based on agronomic performance, especially biomass production and crude protein yield, as well as farmers' perceptions, the cultivars Conway and Glamis would have a high chance to be accepted and adopted in the area, and in other similar conditions. Carrying out trials on animal performance and, especially, on milk production could demonstrate the potential of these productive forages for milk productivity and, thereby, increase chances of adoption by farmers.

Currently, seeds for the tested cultivars are not commercially available in Kenya. Therefore, a deliberate effort should be made to make these, and potentially other fodder oat cultivars, available. Linking with Aberystwyth University in the UK or any other source and facilitating seed availability through the private sector would be key to the uptake and use of these technologies. Future research should focus on development of oats for the Kenyan highlands, and the Kenyan government should facilitate germplasm importation where necessary.

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