

## Forage and economic benefits of Desho (*Pennisetum glaucifolium*) grass-legume intercrops in southern Ethiopia

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### Abstract

Forage grass-legume intercropping is not common in Ethiopia despite its potential to improve forage productivity and farm income. This study evaluated forage mass production and the economic benefits of desho grass (*Pennisetum glaucifolium*)—one of the few native forage crops in Ethiopia—intercropped with alfalfa (*Medicago sativa* L.) and greenleaf desmodium (*Desmodium intortum*) at Hulbareg district in the mid-highlands of southern Ethiopia. The field experiment was conducted during the main growing season of 2020 using a randomized complete block design with three treatments; sole desho grass, desho–alfalfa, and desho–greenleaf desmodium intercrops. Results showed that intercropping increased desho herbage yield by 2.5 t ha<sup>-1</sup> (up to 63% increase) over the sole desho stand. The economic analysis indicated higher net returns from intercropping system, amounting to US\$ 5219 ha<sup>-1</sup> for desho–greenleaf desmodium and US\$ 3866 ha<sup>-1</sup> for desho–alfalfa, compared to US\$ 2567 ha<sup>-1</sup> for the sole desho grass. Partial land equivalent ratio and income equivalent ratio values of desho exceeded 0.5 in intercrops, indicating yield and income advantages for the grass component under intercropping. Overall, desho–greenleaf desmodium intercropping was identified as the most promising option due to its higher herbage yield, superior economic returns, and lower production costs. The findings suggest that integration of legumes into a desho grass-based fodder system can enhance forage productivity and profitability in the Ethiopian mid-highlands. Further validation under farmers' conditions is recommended prior to large-scale promotion.

**Key words:** Desho-legume intercropping, forage mass, partial income equivalent ratio, partial land equivalent ratio, sole desho grass

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### INTRODUCTION

Ensuring a reliable year-round forage supply is a major constraint to improving livestock production in Ethiopia. Improved utilization of promising indigenous grass species offers a potential strategy to mitigate the problem. Among these species, desho grass (*Pennisetum glaucifolium*; previously known as *P. pedicellatum*) has received increasing attention. Desho is a non-invasive perennial grass, adapted to a wide range of agro-ecological conditions. It is well known for its tolerance to moisture stress, and its ability to grow on degraded lands or soil bunds, and is suitable for a cut-and-carry system (Leta et al., 2013; Asmare, 2016;

Maass and Pengelly, 2018). Desho grass is widely cultivated in the mid- and high-altitude regions of southern Ethiopia, where it is predominantly grown in pure stands. Despite its high yield potential and thrives under drought stress and poor soil conditions (Leta et al., 2013), current yields obtained on smallholder farms are generally poor (own observation and focus group interviews; Appendix A). In addition, the relatively high costs associated with establishment and maintenance constrains its production and wider adoption (Leta et al., 2013).

Intercropping desho grass with forage legumes could address several limitations associated with

monocropping that include high initial growing costs, low realized yields relative to potential and high labor demand for gap filling and weed control. Legume integration has also the potential to improve both the nutritive and economic value of the crop (Maass and Pengelly, 2018), suppress weeds and improve land use efficiency (Chimonyo et al., 2016; Gitari et al., 2020; Glaze-corcoran et al., 2020). Hence, the inclusion of forage legumes into the existing desho grass fodder production system could be a viable option to improving forage supply and cash income for smallholder farmers. Alfalfa (*Medicago sativa* L.) and greenleaf desmodium (*Desmodium intortum*) could be suitable companion perennial legumes for desho grass in Ethiopia because of their wide adaptability (Assefa et al., 2012; Mengistu et al., 2017).

However, forage grass-legume intercropping remains rarely practiced or studied in Ethiopia. In southern Ethiopia, for example, planted forages including desho are commonly grown in monocultures (which is also a widespread focus for current pasture and forage research as well (Asmare 2016; Feyissa et al., 2022). Moreover, research in Ethiopia predominantly focused on the most commonly practiced cereal-grain legume intercrops used for human consumption, with limited attention given to forage crop combinations.

Therefore, this study aimed to evaluate the forage mass production and economic benefits of desho grass intercropped with alfalfa and greenleaf desmodium at Hulbareg, a site representative of the mid-highlands agroecological zone of southern Ethiopia.

## MATERIALS AND METHODS

### Site Description

The experiment was conducted at the Farmers' Training Center Demonstration Field in Hulbareg district, Ethiopia (7°58'19" N, 38°37'59" E; 1450 m above sea level) during the period from April to July 2020. The study area is characterized by a cereal-livestock mixed system within the tepid to cool sub-humid mid highlands agroecological zone of Southern Highlands (MoA, 1998; Elias, 2016). The rainfall during the 2020/21 growing

seasons was 1200 mm and the mean annual temperature was 24°C. The dominant soil is a clay loam.

### Treatments and Experimental Design

The treatments comprised of: (i) sole desho grass (*Pennisetum glaucifolium*); (ii) desho intercropped with alfalfa (*Medicago sativa* L.); and (iii) desho intercropped with greenleaf desmodium (*Desmodium intortum*). The forages were planted in the first week of April and harvested in early July. Desho was planted using rooted splits (each approximately 0.3 m in height) at spacing of 0.5 × 0.5 m under sole cropping. In the intercrops, desho was planted at spacing of 1 x 0.5 m. One row of alfalfa and greenleaf desmodium was drilled between the desho grass rows at a recommended seeding rate of 15 and 3 kg ha<sup>-1</sup>, respectively (Mengistu, 2002). The experiment was performed in a randomized complete block design with three blocks. Each plot measured 4 × 3 m. All plots received 100 kg ha<sup>-1</sup> of NPS (19:38:7) at planting and an equivalent amount of urea (46% N) 23 days after planting. Due to the unavailability of rhizobium inoculants, the legumes were sown without inoculation. Weed control was carried out manually in all plots. The weeding was done 23 days after planting and the second weeding was performed 30 days after the first weeding.

### Evaluation of Forage Mass Production, Land and Income Equivalent Ratios

Herbage yield was measured at 90 days after planting (early July 2020). Grasses in the inner two-thirds of each experimental plot were hand-harvested at 8 cm stubble height. Fresh mass (green herbage yield) was weighted immediately in the field. Subsequently, a 500-g representative subsample was oven-dried at 105°C for 24 h to determine dry matter yield of the desho grass. Desho grass is widely cultivated by local farmers both as a source of forage and cash income, as confirmed by farm visits and focus group interviews with local extension officers (Appendix A). Therefore, yield and economic evaluations in this study considered this forage grass as the focus crop.

The advantage of intercropping relative to the sole desho grass in terms of herbage yield and land use

efficiency was quantified using partial land equivalent ratio (pLER). As the primary objective of the study was to evaluate the feasibility of inclusion of legumes into the existing desho grass production system (the focus crop) to improving both forage supply and economic returns (of the crop), pure stands of the legumes were not included in the experimental design (Willey, 1979, 1985). Hence, the LER and income equivalent ratio (IER) (see below) results should be interpreted within this context.

The LER was calculated as:  $pLER_{desho} = Y_{id}/Y_d$  where  $pLER_{desho}$  represents the partial LER of the desho grass and  $Y_{id}$  and  $Y_d$  denote the yield of desho grass in the intercrop and the yield of the sole desho, respectively.

The economic efficiency of the desho grass-legume intercropping system was analyzed using partial income equivalent ratio (pIER). The pIER represents the area needed under sole cropping to produce the same gross or net income, under the same management level, as that obtained from intercropping (Francis, 1986). The IER is conceptually similar to the LER, except that yield is measured in terms of net/gross income, rather than plant productivity. For reason stated above, we employed the partial IER, which was calculated as:  $pIER_{desho} = (Y_{id} * P_d) / (Y_d * P_d)$ ; where  $pIER_{desho}$  is the partial IER of the desho grass and  $Y_{id}$  and  $Y_d$  are the yields of desho (as green feed) in the intercrop and pure stand, respectively.  $P_d$  is the average farm gate price of desho grass, estimated at US\$ 920.12 per unit of fresh herbage (green feed).

### Economic Analysis

A partial budget analysis was conducted to evaluate the economic feasibility of including legumes into the existing desho grass cropping system (CIMMYT, 1988; Mamerto, 2001). The analysis was based on the costs of variable inputs and the economic value of the forage mass produced (i.e. value of desho as green feed) (Table 1). Because desho grass is commonly marketed and utilized as green fodder rather than hay, both the IER (see previous section) and the economic analysis were based on the value green forage production.

The total variable costs included expenditures for fertilizers, rooted-splits, machinery and labour across all treatments, as well as the cost of legume seed for the intercropped treatments. These costs were estimated using prevailing field prices at the time of the experiment (Table 1). Gross income was calculated by multiplying the green herbage yield ( $t\ ha^{-1}$ ) with the field price of US\$ 920.12 for desho fodder at harvest. Net return was determined as the difference between gross income and total variable costs. Costs associated with plowing, harvesting and fertilizers were uniform across treatments and were thus excluded from the analysis, as they did not contribute to differences in economic returns among treatments. All monetary values were converted to US\$ at the 2020 average exchange rate (US\$ 1.0 = Ethiopian Birr (ETB) 34.95). Benefit/cost ratio was calculated by dividing gross income by total variable costs. A benefit/cost ratio  $>1$  indicates a treatment whose benefits outweigh the costs, making the treatment a viable option for on-farm forage production, while those  $< 1$  denote a treatment whose costs exceed the benefits hence, adopting the treatment would not be a worthwhile option (i.e. not cost effective) (Kebede et al., 2024).

### Statistical Analysis

One-way ANOVA using the GLM procedure of IBM SPSS Statistics (version 22) was used to determine the fixed effects of treatments on forage mass production (herbage yield of the main crop), net returns and production costs, and benefit/cost ratio. Although we were interested on the main factor (i.e. the treatment), blocks (treated as a fixed effect; Dixon, 2016) were kept in the model (Dean and Voss, 1999; Frey et al., 2024). Means among treatments were compared using the least significant difference (LSD) test at  $p < 0.05$ . The data from this study is deposited in the Mendeley Data repository (Nasir et al., 2025).

**Table 1. Variable costs of production and field price of desho green fodder (US\$) used in the economic analysis**

Items	Unit	Field price unit <sup>-1</sup>	Sole desho		Desho + alfalfa		Desho + GD	
			Quantity	Amount (US\$)	Quantity	Amount (US\$)	Quantity	Amount (US\$)
<i>Purchased inputs</i>								
Alfalfa seed	kg ha <sup>-1</sup>	7.44	–	–	15.00	111.59	–	–
GF seed	kg ha <sup>-1</sup>	20.03	–	–	–	–	3.00	60.09
Desho rooted splits	plants ha <sup>-1</sup>	0.04	29167	1030.04	17500	618.03	17500	618.03
<i>Total input costs</i>				1030.04		729.61		678.11
<i>Labour input</i>								
	Days ha <sup>-1</sup>							
Planting <sup>a</sup>		1.61	19.07	30.70	11.44	18.42	11.44	18.42
Weeding	First <sup>b</sup>	1.5	17.67	26.51	12.40	18.60	16.00	24.00
	Second	1.5	16.14	24.21	16.14	24.21	13.35	20.03
<i>Total labour costs</i>				81.42		61.23		62.45
<i>Total variable costs<sup>c</sup></i>				1111.46		790.84		740.56
<i>Output</i>								
Green fodder <sup>d</sup>	t ha <sup>-1</sup>	920.18						

GD, Greenleaf desmodium. <sup>a</sup>Includes labour required to apply NPS. <sup>b</sup>Includes labour required to apply urea. <sup>c</sup>Costs that did not vary by treatment were excluded from this calculation. <sup>d</sup>The value of desho grass as green fodder (fresh forage) was used in the economic evaluation of tested treatments.

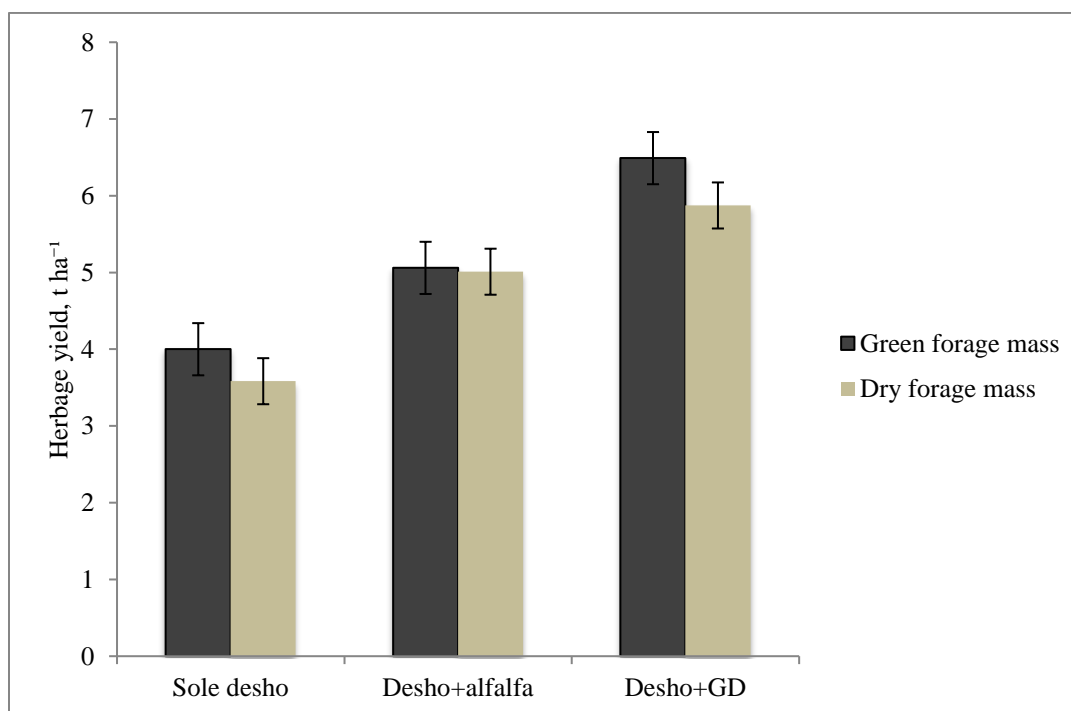
## RESULTS

### Produced Herbage Mass

Desho grass produced greater herbage yield (notably dry mass) under intercropping than in the corresponding pure stand (Figure 1). The highest fresh herbage yield was obtained when desho was intercropped with greenleaf desmodium (6.49 t ha<sup>-1</sup>), which was significantly higher than both the deso-alfalfa intercrop and the sole desho treatment ( $p < 0.05$ ). Although the difference between sole desho and desho-alfalfa intercrop was not significant ( $p = 0.67$ ), fresh herbage yield was slightly higher under intercropping than under sole desho (5.06 versus 4.0 t ha<sup>-1</sup>). Herbage dry matter yield was significantly higher in both desho-greenleaf desmodium/alfalfa intercrops compared with sole desho, with no significant difference between the two intercrops. Notably, intercropping desho with greenleaf desmodium increased fresh and dry herbage yields by 2.5 t ha<sup>-1</sup> (~63 % increase) and 2.29 t ha<sup>-1</sup> (64 % increase) respectively, relative to the sole desho (Figure 1).

### Economic Returns

Net return differed among treatments, with both intercropping systems generating significantly higher net returns than sole desho (Table 2). The, desho-greenleaf desmodium intercrop earned the highest net return compared to the sole desho (US\$ 5219 versus US\$ 2567 ha<sup>-1</sup>) and the desho-alfalfa intercrop (US\$ 5219 versus US\$ 3866 ha<sup>-1</sup>). In contrast, sole desho incurred significantly higher total variable costs (by US\$ 321 to 354 ha<sup>-1</sup>), mainly due to greater labour requirements for planting and weeding and higher costs of planting materials (Table 1). Benefit/cost ratio differed among treatments with the highest significant value recorded for desho-greenleaf desmodium (6.9), whereas sole desho had the least ratio (2.3). Overall, the desho-greenleaf desmodium intercrop generated US\$ 1353 more net return than the desho-alfalfa intercrop, indicating its potential as a promising option, in terms of both profitability and production costs, for further evaluation.



**Figure 1. Forage mass production of desho grass grown in sole cropping and in desho-legume intercrops.** Bars sharing same letter within each yield component are not significantly different at  $p < 0.05$ . Bars represent standard error of the mean. GD, Greenleaf desmodium.

**Table 2. Economic benefits of desho grass grown in sole cropping and in desho-legume intercrops**

	Treatment			LSD (0.05)	p value
	Sole desho	Desho alfalfa	+ Desho GF		
Green forage mass, t ha <sup>-1</sup> *,†	4.00	5.06	6.49		
Gross income (GI), US\$ ha <sup>-1</sup>	3678.81a	4656.97a	5976.18	1099.80	0.011
Total variable costs (TVC), US\$ ha <sup>-1</sup>	1111.5	790.84a	757.32a	38.32	<0.001
Net return (GI- TVC)§	2567.35	3866.13	5218.86	1106.52	0.007
Benefit/cost ratio	2.31	4.89	6.89	1.47	0.002

\*Adjusted yield. †See Figure 1 for mean comparison. §Value of desho as green feed was used to estimate the net returns from the fodder. Values with a common letter within the same row are not significantly different at  $p < 0.05$ . GD, Greenleaf desmodium

### Land and Income Equivalent Ratios of Intercrops

The partial LER values of desho grass were markedly higher than 0.5 (Table 3), indicating that the herbage yield of the desho grass under intercropping exceeded half the yield obtained from the sole desho. Although differences in partial LER between treatments were not included in the objective of the study, important differences were found. Of the tested intercrop treatments, the desho-greenleaf desmodium intercrop had the highest LER (1.63) in comparison to desho-alfalfa (1.27) suggesting superior productivity per unit

area when desho was grown in association with greenleaf desmodium.

A similar pattern was observed for the partial IER (Table 3). In all intercrop treatments, the partial IER values for desho were exceeded 0.5, further confirming the economic advantage of desho-legume intercropping (Table 2). The highest partial IER value for desho was obtained from the desho-greenleaf desmodium intercropping, indicating its greater economic efficiency relative to the desho-alfalfa combination.

**Table 3. Partial land and income equivalent ratios of desho grass intercropped with alfalfa or greenleaf desmodium.**

Treatment	Partial LER (desho)	Partial IER (desho)
Desho + alfalfa	1.27	1.27
Desho + GD	1.63	1.63

GD, Greenleaf desmodium

## DISCUSSION

### Forage Production and Economic Benefits of Desho-Legume Intercropping

Despite the lower net area devoted to the crop under intercropping, desho grass in intercrops was generally more productive and profitable than in the corresponding pure stand. Among the intercrop treatments, desho-greenleaf desmodium improved desho fresh herbage and dry matter yields by 63% and 64% respectively compared with the sole crop.

Thus, there is a potential to intensify desho grass forage production in the study location. The lowest forage mass production (dry mass, for example) recorded in the present study, 5.05 t ha<sup>-1</sup> in deso-alfalfa intercrop (cf. Figure 1), was higher than yields reported for desho-vetch intercrops under comparable agro-ecological conditions in Ethiopia, where desho produced only 2.29–3.58 t ha<sup>-1</sup> of dry matter (Abera et al., 2021). This suggests that that the selected legume species

evaluated in the present study are generally compatible with the desho grass. Nonetheless, of the tested options, desho-greenleaf desmodium emerged as the most promising intercrop and warrants further evaluation. The suitability of greenleaf desmodium for integration with native grasses for improved forage production under east African highlands conditions has been acknowledged in previous studies (Mwangi et al., 2004; Jørgensen et al., 2023). The better herbage yields obtained under intercropping are likely attributed to improved soil nitrogen availability resulting from biological fixation by the legumes (e.g., Jensen et al., 2020; Rao & Mathuva, 2000; Tow & Lazenby, 2001).

The higher net returns obtained under desho-legume intercropping systems indicate clear economic gain from legume inclusion. Reduced input costs compared to the conventional desho cropping system, together with increased herbage yields of desho in the intercrops contributed to the improved net returns. In contrast, lower net returns from sole desho resulted from relatively low herbage yields and higher production costs (cf. Table 2), making this system economically less attractive. Consequently farmers could benefit more from intercropping desho with legumes, especially greenleaf desmodium. The desho-greenleaf desmodium treatment increased net returns by 103% over the sole desho. Similarly, the benefit/cost ratio, an indicator of the economic efficiency, was highest for the desho-greenleaf desmodium treatment, confirming its superior profitability.

#### **Effect of Legume Inclusion on Land and Income Equivalent Ratios**

The partial LER of desho exceeded 0.5 in both desho-alfalfa and desho-greenleaf desmodium intercrops, suggesting that there was an advantage for the desho in the intercropping (Pelzer et al., 2014). The higher partial LER values observed under the intercrops indicate that the inclusion of legume in the sole desho system favored faster crop establishment and early plant growth and plant vigor as reflected by early biomass production of the intercropped grass. Although comparable data for direct comparison are lacking, extensive evidence from cereal-

legume intercropping evaluation, higher partial LER values observed in the present study were presumably due to a positive effect of legumes on the companion grass. These effects may include reduced interspecific competition and weed pressure, as well as improved nitrogen availability (Chen et al., 2004; Kermah et al., 2017; Gitari et al., 2020; Xu et al., 2020). The highest partial LER value of 1.63 was obtained in the desho-greenleaf desmodium intercrop (cf. Table 3). Similarly, the higher partial IER values recorded for desho in both intercrop treatments were an indication of economic gain with legume integration, probably due to the positive effect of legumes on desho when grown in association. A partial IER >0.5 implies that intercropping resulted in greater economic efficiency compared with sole cropping. This larger partial IER of the grass might also mean that the intercropped desho benefited from a legume inclusion (Dzvene et al., 2022). Among the tested intercrops, desho-greenleaf desmodium was the most remunerative with a higher IER value (1.63) compared with the other intercrop treatment.

#### **CONCLUSIONS**

Intercropping desho grass with legumes provides a viable alternative to sole desho cropping. Irrespective of legume species, desho grown in intercrops produced higher forage mass and achieved superior net returns compared with sole cropping. The observation that partial LER and IER values of desho were higher in intercrops showed that there can also be advantages to desho in intercropping. Among the tested treatments, the desho-greenleaf desmodium intercrop was particularly promising due to its higher herbage yields, improved net returns, and reduced production costs. However, the findings are based on a single-season experiment, which is a limitation of the present study. Future research should therefore validate the agronomic and economic performance of this promising intercrop under farmers' conditions prior to wider recommendation and adoption.

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### CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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### APPENDIX

#### Appendix A. Results of Focus Group Interview and Preliminary Field Observation

To elucidate aspects of the local farming system, problems and potential solutions related to livestock feed resources, we conducted field observations and focus group discussion with key informants in three purposively selected *kebeles* (the smallest administrative unit in Ethiopia) of the district where desho grass (*Pennisetum glaucifolium*) cultivation is prevalent. The state of desho production, its role within the farm feedbase and the problems faced in growing the crop were also discussed with the participants. These activities were held prior to the field experimentation. The three *kebeles* were selected because significant number of farmers inhabiting in these *kebeles* were engaged in on-farm desho cultivation. Group interviews with local key informants involved model farmers, *kebele* administrators and extension officers (in charge of forage and livestock production) as well as district livestock extension staffs. General data such as average family size, livestock and number and area of farm fields were obtained from official statistics from the *kebele* level extension offices. The following report analyses the results of this preliminary study.

#### The Farm and Farming System Characteristics

Cereal-based mixed crop-livestock (mostly cattle) farming system is the dominant economic activity in the district. Farmers cultivate maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), teff (*Eragrostis tef* (Zucc.)), and pulses such as haricot beans (*Phaseolus vulgaris* L.) and chickpea (*Cicer arietinum*). Most farmers in the study area owned about 2 ha of land and 6 tropical livestock units

(TLU; equal to 250 kg of body weight). The average family size was 6 people per household. Most households had two land holdings, a homestead plot with a small cropped area, and a larger contiguous cropped area located away from the farmhouse. According to the interview participants and our field observations, the homestead fields were mainly used for growing desho grass and some perennial crops and timber trees while the grain crops were planted in the main crop field. Natural pasture and crop residues together with cultivated grasses (primarily desho grass) provide the bulk of feed for livestock. Feed is the main limiting resource for livestock production in the area, mentioned by all interview participants. They also mentioned that intra-year variability in feed supply is common in the area. However, based on our field observations and informal interviews with the extension officers, there is a possibility to improve forage availability through intensification of desho grass production.

#### Current State of Desho Grass Production and Factors Limiting its Production and Use

The district can be considered one of the areas where cultivated forage grass is widely practiced in Ethiopia. During the study year (i.e., 2020), for example, about one-third of the farm households in the district cultivated desho grass on-farm (not published data). This figure is large compared to the national average of less than 1% (CSA, 2017). Desho grass production in the area was largely rain-fed. The grass is one of the most important sources of fodder, planted on homestead fields (though the specific cropping pattern varies among farmers) and is also a cash crop for some farmers who sell the fodder to other farmers during periods of shortage. Most farmers grew desho in monocultures (Figure A1b) while few farmers planted in between rows of perennial crops such as *chat* (*Catha edulis*), Banana and timber trees (Figure A1a). As mentioned above, desho is grown for livestock feed and is harvested as greenchop. Greenchop is cut directly from the field and is fed immediately to animals or sold to other farmers (during periods of shortage). Extension officers involved in the discussion unanimously indicated that, although the grass has the potential to provide stable forage supply and improve profitability for farmers, current yields on

farmer fields are often poor. The low yields of desho were probably due to inadequate management of the crop and limited input use, among others. For example, weeding of desho grass was uncommon in the area, mainly attributed to lack of awareness and shortage of labor as revealed by all the interview participants. The field

experiment was thus initiated to identify a cropping system that can increase yields of this native grass and simultaneously contribute to reduced input/labor costs linked to the conventional production system of the grass.



**Figure A1.** Images of the conventional desho cultivation practices at Hulbareg, Ethiopia: (a) desho grown between rows of perennial crops and timber trees; (b) desho grown in pure stand. Photos: A. Nasir.

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