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Oat–Field Pea Intercropping for Sustainable Oat Production: Effect on Yield, Nutritive Value and Environmental Impact

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Abstract: The aim of the study is to evaluate the effect of Oat–field pea intercropping on the yield, nutritive value, and environmental impact of oat grown under a reduced level of nitrogen fertilisation. The trial was laid out in a randomized complete block design with the following treatments: oat-0 (oat (*Avena sativa* L., SRCP X 80 Ab 2291 variety) without N fertilization (urea)), oat-23 (oat fertilised with 23 kg N/ha), oat-46 (oat fertilised with 46 kg N/ha), O1P1 (oat intercropped with field pea (*Pisum sativum* L., local variety) a ratio of 1:1), O1P2 (oat intercropped with field pea a ratio of 1:2), and O2P1 (oat intercropped with field pea at a ratio of 2:1). All of the experimental plots received standard husbandry practices except for nitrogen fertilisation. Soil pH, organic matter, total nitrogen, available phosphorus, and organic carbon were determined before and after planting. The effect of nitrogen fertilization and intercropping of oat with field pea on carbon footprint, acidification footprint, eutrophication footprint, and human toxicity footprint was calculated for each plot. Oat-0 significantly reduced the total nitrogen content of the soil, while there was no significant effect of the other treatments. O2P1 significantly out-yielded all control groups; however, it was not significantly different from fertilisation treatments. Intercropping with field pea did not significantly increase the cost of production of dry matter, crude protein, or dry matter digestibility compared to control groups. Intercropping with field pea significantly reduced the carbon footprint, acidification, eutrophication, and human toxicity footprint compared to the control groups. Therefore, oat–field pea intercrops are recommended for the production of high-quality forage at low N input with reduced environmental impact.

Keywords: *Avena sativa*; forage; carbon; acidification; eutrophication; human toxicity

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1. Introduction

Ethiopia has large herds of sheep (42 M head), cattle (70 M head), and goat 50 M head) [1]. However, these livestock do not perform to their genetic potential, mainly due to feeding and management factors. Feed resources produced in Ethiopia meet only 48% of the dry matter requirement of the national livestock herd [2]. Livestock in Ethiopia are kept in smallholder farming systems where dual arable crop and livestock production is common practice [3]. Increasing on-farm feed production in these mixed farming systems would increase the efficiency of meat and milk production and decrease feeding costs by reducing dependency on the purchased feed. Furthermore, additional income could be generated by selling off any surplus biomass.

In Ethiopia, oat (*Avena sativa* L.) is an important fodder crop. Its high tolerance to challenging abiotic conditions makes oat a viable crop in areas that are deemed marginal land due to soil type, temperature, and drought [4,5]. Ethiopia annually produces ~99,000 t of oat forage (adopted from [1] using harvest index of 1.5 [6]). Oat forage is highly digested by ruminants (0.601 in vivo organic matter digestibility), having both a high content of energy (8.3 MJ/kg) and protein (91 g/kg) [7].

Monocropping is common practice in the agricultural farming systems of Ethiopia; however, the intensity of monocropping varies among regions [8]. Monocropping, combined with a low fertilization rate, is shown to negatively affect soil quality as it leads to the depletion of soil organic matter [9]. Lower fodder yield, poor nutritive value, and poor utilization of light, water, and nutrients result from monocropping [10]. Therefore, inorganic fertilisation was promoted as a solution to mitigate the consequences of monocropping on soil health and crop productivity [11]. Nitrogen fertilisation was subsequently reported to improve the biomass yield and nutritive value of forage (timothy grass [12]). However, nitrogen fertilisation is associated with both an increase in greenhouse gas emission and a decrease in economic return. References [13–15] reported that chemical fertilizer application had led to substantial nitrogen losses in the form of N_2, N_2O, and NO_x through runoff, volatilization, leaching, and infiltration into the soil profile, playing a large part in global greenhouse gas emission. Inorganic fertilization (including nitrogen fertilisation) also alters the population structure and diversity of the soil bacterial community (e.g., Nitrospiraceae and Chitinophagaceae) due to its degradation of polysaccharides and N transformation in the soil [16]. Moreover, although adoption rates for inorganic fertiliser among Ethiopian farmers are relatively high, the rate of application is considered suboptimal compared to the recommended practice [17]. Thus, decreasing the dependency on nitrogen fertilization is critical.

Intercropping improves nutrients accumulation in the deep layer of the soil, leading to increased aerial portions and larger root system of the plant, thereby offering more nutrients to the adjacent plants [18]. The intercropping of palisade grass with soybean [19] and faba bean with barley [20] resulted in more revenue and yield than mono-cropped counterparts. Similarly, an increased dry matter yield and crude protein content of maize was achieved when it was intercropped with different legume species [10]. Therefore, intercropping oat with field pea might improve oat forage production and quality while minimising the need for additional nitrogen fertilisation.

No studies have been reported to date on the effect of intercropping versus monocropping on the sustainabily of oat forage production under low nitrogen fertilization.

The goal of the current study is to determine the viability of intercropping with field pea as a sustainable option for oat forage production under reduced nitrogen fertilisation.

2. Material and Methods

2.1. Study Site

The trial was conducted during the July 2019 oat cropping season at Jimma University Technology Institute (latitude: 7°41′ N; longitude: 36°48′ E. altitude: 1950 m.a.s.l). Physical and chemical properties of the trial soil are presented in Table 1. The trial plot was cropped with field pea in the previous season. Minimum temperature, maximum temperature, and annual rainfall during the cropping season were 14 °C, 30 °C, and 1414 mm, respectively. Soil particle size fractions of the experimental site were 38% sand, 32% clay, and 30% silt, and the soil texture class was clay loam.

Table 1. Effect of Oat–field pea intercropping on physio-chemical characteristics of soil.

O1-P1	pH	OC	TN	*p*	OM	CEC
Before sowing	5.29	3.49	0.261	72.9	4.19	23.3
After harvest	5.43	3.45	0.25	73.6	4.2	23.5
SEM	0.481	0.355	0.014	3.4	0.51	1.59
O2-P1						
Before sowing	5.75	3.65	0.245	67.9	4.65	25.1
After harvest	5.72	3.68	0.24	68.3	4.68	25.4
SEM	0.51	0.376	0.0148	3.6	0.54	1.68
O1-P2						
Before sowing	7.69	3.47	0.249	77	4.3	29.4
After harvest	5.75	3.48	0.25	76.8	4.29	29.2
SEM	0.49	0.344	0.012	3.33	0.538	1.65
Oat-0						
Before sowing	5.19	2.76	0.25	64	4.8	24.1
After harvest	5.22	2.78	0.201 *	64.1	4.79	24.4
SEM	0.497	0.349	0.013	3.382	0.551	1.66
Oat-23						
Before sowing	5.24	3.55	0.274	66.5	5.34	25.7
After harvest	5.25	3.56	0.27	66.7	5.31	25.8
SEM	0.49	0.344	0.013	3.33	0.543	1.64
Oat-46						
Before sowing						
After harvest	5.35	3.1	0.26	63.4	3.61	27.7
SEM	0.491	0.345	0.012	3.34	0.54	1.65

CEC, cation exchange capacity (%); OM, Organic matter (%); OC, organic carbon (%); TN, total nitrogen (%); P, Available phosphorus (ppm); *, Significantly different from the before sowing.

2.2. Crop Management and Experimental Design

All experimental plots were ploughed, disk harrowed, and cultivated. The experimental plots had similar crop husbandry throughout the trial. The trial was laid out in a randomized complete block design with the following treatments: oat-0 (oat (*Avena sativa* L., SRCP X 80 Ab 2291 variety) without N fertilization), oat-23 (oat fertilised with 23 kg N/ha), oat-46 (oat fertilised with 46 kg N/ha), O1:P1 (oat intercropped with field pea (Pisum sativum L., local variety) a ratio of 1:1), O1:P2 (oat intercropped with field pea a ratio of 1:2), and O2:P1 (oat intercropped with field pea a ratio of 2:1). The intercropping ratios were adopted from [21]. The nitrogen fertiliser used in the trial was urea 46% N. The level of N fertilization of the positive control was adopted from [22].

Each treatment was replicated 3 times. Plot size, inter-row spacing, the spacing between the plots, and the space between replicates (blocks) were 3 m × 2 m, 30 cm, and 1 and 1.5 m, respectively. Oat and field pea were planted in 10 rows/plot at a rate of 80 kg/ha and 70 kg/ha, respectively. The experimental plots were sown in the first week of July 2019. None of the experimental plots received irrigation while weeds were manually removed.

2.3. Data Collection, Sampling and Laboratory Analysis

Soil samples were collected from each of the 18 plots at a depth of 0 cm–30 cm two times, one before sowing and one after harvesting. Soil samples were air dried and sieved through 2 mm diameter sieve before chemical analysis. Soil pH was determined at 1:2.5 soil to water ratio using a pH digital meter. Soil organic matter was determined according to Walkley–Black chromic acid wet oxidation method [23]. Briefly, the oxidisable matter in the soil was oxidised by 1 N $K_2Cr_2O_7$ solution and the remaining chromate was determined spectrophotometrically at 600 nm wavelength. The organic carbon content was calculated from the organic matter content (soil organic matter contained 58% carbon [24]). Total soil nitrogen was analysed according to Kjeldhal method. Available phosphorus was determined by the Olsen bicarbonate extraction method [25]. Briefly, a mixture of 2.5 g of air-dried soil and 50 mL of 0.5 molar sodium bicarbonate (adjusted to pH 8.3–8.5) solution was shaken for half an hour. Molybdate-ascorbic acid reagent was used to develop a blue colour in the mixture and P concentration was measured calorimetrically (Brinkman PC 900 probe colorimeter at 880 nm). Cation exchange capacity was measured according to [26].

Oat biomass was manually harvested at heading (during the second week of October 2019) to maximise dry matter yield and nutritional quality. After harvest, fresh biomass yield of every plot was partitioned into stem and leaf, oven-dried at 65 °C overnight to achieve constant weight, then weighed to calculate dry matter yield and leaf to stem ratio.

Representative plant samples from biomass harvested from each plot were oven dried at 65 °C for 72 h. The dried samples were ground to pass through 1 mm sieve and stored until the nutritional analysis. The analysis of feed samples was undertaken at Jimma University in the Post-harvest Lab. Dry matter and ash of all forage samples were determined according to [27] (method 934.01 and 942.05, respectively). Nitrogen content of forage samples was determined according to method 954.01 of AOAC (2006). The nitrogen content of forage samples was converted into crude protein content using 6.26 factor. Acid detergent fibre was determined according to [28] and expressed as residual ash exclusive. The dry matter digestibility was calculated from acid detergent fibre using the equation of [29].

2.4. Environmental Impact Calculations

The environmental impact of each plot was assumed to result from ploughing and urea fertilisation. Agribalyse Life Cycle Inventory [30] (CML-IA baseline with mass allocation method) was used to obtain the environmental impact of diesel and urea fertilizer grade. Then, the environmental impact footprint of each experimental plot was calculated and normalised for one ton of dry matter, crude protein, and in vitro dry matter digestibility. The functional units were one ton of dry matter, crude protein, and dry matter digestibility. The environmental impact footprints in the study were calculated from sowing to harvest. The environmental impacts calculation did not include sources other than nitrogen fertilization and ploughing.

2.5. Statistical Analysis

Data of soil analyses before sowing were compiled with those after harvest in 5 datasets. Each of these datasets was analysed using independent samples T test. The rest of the study data were analysed using the following model:

$$Y_{ij} = M + TRT_i + Block_j + E_{ij}$$

where Y_{ij} is the response variable (soil analyses, forage yield . . . .), M is the overall mean of the response variable, $Block_j$ is the effect of block, TRT_i is the effect of the experimental treatments, and E_{ij} is the residual.

3. Results

3.1. Soil Analysis

Before sowing, there was no significant effect of the treatment on the soil pH, organic matter, available phosphorus, cation exchange capacity, nitrogen, and organic carbon ($p > 0.05$), as shown in Table 1. Oat-0 significantly reduced the total nitrogen content of the soil after harvest.

3.2. Yield

The effect of intercropping with field pea and N fertilisation on the oat forage yield is shown in Table 2. Oat intercropped with field pea (regardless of the intercropping ratio) yielded a significantly higher dry matter, crude protein, and dry mater digestibility compared to oat-0. The dry matter yields of O1P1 and O1P2 were significantly higher than that of sole oat. The crude protein yield of O2P1 significantly outyielded the control groups. The cost of production of one t of dry matter, crude protein, and dry matter digestibility of oat forage intercropped with field pea was significantly less compared to oat-0. Intercropping with field pea did not significantly increase the production cost of dry matter, crude protein, or dry matter digestibility compared to the control groups.

Table 2. Effect of nitrogen fertilisation and intercropping with field pea on forage yield of oat.

	Oat-0	**Oat-23**	**Oat-46**	**O1P1**	**O1P2**	**O2P1**	**SEM**
Forage yield (t/ha)							
Dry matter	4.16 ^{c}	5.01 ^{bc}	6.47 ^{a}	5.94 ^{ab}	5.83 ^{ab}	5.33 ^{b}	0.358
Crude protein	0.347 ^{d}	0.45 ^{cd}	0.618 ^{b}	0.573 ^{ab}	0.624 ^{b}	0.501 ^{ac}	0.039
Dry matter digestibility	2.41 d	2.89 ^{cd}	3.79 ^{b}	3.49 ^{ab}	3.46 ^{ab}	3.11 ^{ac}	0.214
Cost of production (USD/t)							
Dry matter	6.55 ^{c}	5.52 ^{b}	4.36 ^{a}	4.59 ^{a}	4.64 ^{ab}	5.11 ^{ab}	0.269
Crude protein	79.2 ^{c}	61.6 ^{b}	45.7 ^{a}	47.7 ^{a}	43.6 ^{a}	54.5 ^{ab}	3.33
Dry matter digestibility	11.3 ^{c}	9.6 ^{b}	7.5 ^{a}	7.8 ^{a}	7.8 ^{a}	8.8 ^{ab}	0.49
Nutritive value							
Leaf-stem ratio	0.945 ^{c}	0.969 ^{bc}	0.988 ^{b}	1 a^{b}	1.03 ^{a}	0.995 ^{ab}	0.01
Dry matter (g/kg)	863	886	908	88^{9}	897	885	12.3
Ash (g/kg)	114	97	93	99	99	102	5.58
Crude protein (g/kg)	83.1 ^{c}	89.7 ^{bc}	95.5 ^{b}	96.3 ^{b}	107 ^{a}	93.9 ^{b}	2.31
Dry matter digestibility (%)	57.9	57.6	58.5	58.8	59.3	58.4	0.846

Oat-0 sole oat without nitrogen fertilisation, Oat-23, sole oat fertilised with 23 kg N/ha; Oat-46, sole oat fertilised with 46 kg N/ha; O1:P1, oat intercropped with field pea at a ratio of 1:1; O1:P2, oat intercropped with field pea at a ratio of 1:2; O2:P1, oat intercropped with field pea at a ratio of 2:1; SEM, standard error mean. Means within row with different superscripts are significantly different at $p = 0.05$.

3.3. Nutritional Value of Oat Forage

Table 2 presents the effect of intercropping with field pea and nitrogen fertilisation on the nutritive value of oat forage. Intercropping with field pea yielded a significantly higher leaf–stem ratio and crude protein content compared to oat-0. The leaf–stem ratio and crude protein content of O1P2 were significantly higher than in the control groups. The in vitro dry matter digestibility of oat was not significantly affected by the treatment.

3.4. Environmental Impact

Urea fertilisation significantly reduced the carbon footprint of dry matter, crude protein, and dry matter digestibility of oat compared to oat-0 (Table 3). The carbon footprint of the dry matter, crude protein, and dry matter digestibility of oat intercropped with field pea was significantly less compared to oat-0. The carbon footprints of crude protein in O1P1 and O1P2 were significantly less than that of oat-23.

Nitrogen fertilisation significantly decreased the acidification footprint of oat forage yield compared to oat-0. The acidification footprint of dry matter, crude protein, and dry matter digestibility of oat intercropped with field pea was significantly less compared to the control groups.

There was a significant, negative effect of nitrogen fertilisation on the eutrophication footprint of oat forage dry matter, crude protein, and dry matter digestibility. Intercropping oat with field pea also significantly reduced the eutrophication footprint of dry matter, crude protein, and dry matter digestibility compared to oat-0.

There was no significant effect of nitrogen fertilisation on the human toxicity footprint of dry matter, crude protein, and dry matter digestibility compared to oat-0. Oat intercropped with field pea had a significantly lower human toxicity footprint compared to the control groups.

Table 3. Effect of nitrogen fertilisation and intercropping with field pea on carbon footprint, acidification, eutrophication, and human toxicity of oat forage.

	Oat-0	**Oat-23**	**Oat-46**	**O1P1**	**O1P2**	**O2P1**	**SEM**
Global warming potential (kg CO_2 eq/t)							
Dry matter	18.9 ^{c}	15.7 ^{b}	12.2 ^{a}	13.2 ^{ab}	13.4 ^{ab}	14.7 ^{ab}	0.767
Crude protein	228 ^{c}	175 ^{b}	128 ^{a}	137 ^{a}	126 ^{a}	157 ^{ab}	9.54
Dry matter digestibility	32.7 ^{c}	27.2 ^{b}	20.8 ^{a}	22.5 ^{ab}	22.6 ^{ab}	25.2 ^{ab}	1.4
Acidification (kg SO_2 ceq/t)							
Dry matter	0.103 ^{d}	0.193 ^{c}	0.232 ^{b}	0.072 ^{a}	0.073 ^{a}	0.08 ^{a}	0.008
Crude protein	1.24 ^{d}	2.15 ^{c}	2.43 ^{b}	0.75 ^{a}	0.69 ^{a}	0.86 ^{a}	0.083
Dry matter digestibility	0.178 ^{d}	0.335 ^{c}	0.397 ^{b}	0.123 ^{a}	0.123 ^{a}	0.138 ^{a}	0.015
Eutrophication (kg PO_4^{-3} eq/t)							
Dry matter	0.027 ^{c}	0.022 ^{b}	0.017 ^{a}	0.019 ^{ab}	0.019 ^{ab}	0.021 ^{ab}	0.001
Crude protein	0.323 ^{c}	0.247 ^{b}	0.181 ^{a}	0.194 ^{a}	0.178 ^{a}	0.222 ^{ab}	0.013
Dry matter digestibility	0.046 ^{c}	0.039 ^{b}	0.03 ^{a}	0.032 ^{ab}	0.032 ^{ab}	0.036 ^{ab}	0.002
Human toxicity (kg 1, 4-dichlorobenzene eq/t)							
Dry matter	0.247 ^{b}	0.257 ^{b}	0.239 ^{b}	0.173 ^{a}	0.175 ^{a}	0.193 ^{a}	0.012
Crude protein	2.99 ^{c}	2.87 ^{c}	2.5 ^{bc}	1.8 ^{a}	1.65 ^{a}	2.06 ^{ab}	0.137
Dry matter digestibility	0.428 ^{b}	0.446 ^{b}	0.409 ^{b}	0.295 ^{a}	0.296 ^{a}	0.331 ^{a}	0.021

Oat-0 sole oat without nitrogen fertilisation, Oat-23, sole oat fertilised with 23 kg N/ha; Oat-46, sole oat fertilised with 46 kg N/ha; O1P1, oat intercropped with field pea at a ratio of 1:1; O1P2, oat intercropped with field pea at a ratio of 1:2; O2P1, oat intercropped with field pea at a ratio of 2:1; SEM, standard error mean. Means within row with different superscripts are significantly different at $p = 0.05$.

4. Discussion

The current study shows that O1P1 and O1P2 produced comparable biomass and nutrients (crude protein and dry matter digestibility) at a much lower cost than the fertilised oat. Intercropping with field pea improved the forage yield of dry matter, crude protein, and dry matter digestibility by ~1.78 t, 0.226 t, and 1.08, respectively. Reference [31] reported that 79 g crude protein in the diet is required to produce one kg of 4% fat caw milk. Therefore, the increase in crude protein yield would be translated into ~2860 kg of milk for each ha grown by oat. Furthermore, intercropping with field pea (O1P1) reduced the cost of producing oat forage dry matter, crude protein, and dry matter digestibility by 30%, 40%, and 30%, respectively.

The positive effects of nitrogen fertilizer on forage yield and nutritive value in the current study are moderately consistent with those reported in other similar studies [32–34]. Field pea is reported to fix 111 kg N/ha/year, although the volume of fixed N is not expected to be entirely transferred to the co-cultivated plant. From the fixed atmospheric N, 0–70% is reported to be transferred below ground to the neighbouring plants through decomposition of legume roots and nodules [34]. Reference [35] reported that pea transferred 19% N to the co-cultivated barley after 70 days of growing. This provision of fixed nitrogen by peas in an intercropping situation may explain the improvement in oat forage yield and nutritive value associated with Oat–field pea intercropping in the current study. This proposed mechanism is further supported by reports that the intercropping of Poaceae with alfalfa resulted in RuBPCase and NR activities, leading to an increase in root surface area, root length, and other root system variables [36].

Feed resources in Ethiopia could supply considerably more than the current 48% of the dry matter requirement of the national livestock herd [2]. While forage production using high levels of inorganic fertilisation is an effective route to increase the volume of Ethiopian forage production, this practice is associated with a high environmental impact; evidenced by an increase in greenhouse gas emissions, land use, fossil fuel energy use, eutrophication potential, and acidification potential [37]. Additionally, fertiliser application below the recommended levels by Ethiopian farmers indicates that this may not be an economically viable route.

Therefore, the low input intercropping system with reduced inorganic fertilisation is suggested as a viable alternative to ensure environmental sustainability in food and feed crops [38]. In this study, the intercropping of oat with field pea reduced the carbon footprint, acidification footprint, eutrophication footprint, and human toxicity footprint of oat production. This is in agreement with previous studies which reported on reduction in the environmental impact of food and forage production of cereal crops when intercropped with legume crops (soybean–maize intercrop [39,40], soybean–sugarcane intercrop [41], peanut–cotton–wheat intercrop [42], arugula–beet intercrop [43], and forage legume vs. perennial grass intercrop [44]). The reason behind the reduction in the environmental impact of oat-pea intercrops is that the intercropping maintained forage production while nitrogen fertilisation, which is the main reason for the negative environmental impacts, was not applied.

Soil nutrients such as nitrogen, organic carbon, phosphorus, potassium, and organic matter play a major role in nutrient metabolism in plants leading to enhanced productivity of food and feed traits [45]. Accordingly, crop production, without compensating nutrients absorbed by plants, will lead to deterioration in soil productivity.

The current study showed that both nitrogen fertilisation and intercropping with field pea compensated for soil nitrogen absorbed by plant biomass growth. It seems that nitrogen utilized by the forage is contributed by the field pea since the soil total nitrogen content remained unchanged post-cultivation. This is in agreement with studies in the literature where the intercropping of cereals and legume crops improved soil nutrient profile compared to cereal monocrop [46–49].

Sustainable production is supported by three pillars, social, economic, and environmental [49]. Overall, intercropping with field pea improved oat forage yield and nutritive value, providing the on-farm feed resources needed to improve milk and meat production. Therefore, this approach would improve the overall economic and health levels of poor households in mixed systems. Furthermore, this improvement will not be associated with the negative environmental impacts known to result from the use of inorganic nitrogen fertilisation. The current study indicates that intercropping oats as a forage crop with field pea as a nitrogen-fixing legume crop is an economically and environmentally viable route for Ethiopia to achieve UN Sustainable Development Goal 12: Responsible Production and Consumption without deviating from the current approach of small scale, mixed farming systems.

5. Conclusions

Oat–field pea intercropping (O1P1, O1P2 or O2P1) improved oat forage yield and nutritive value, and decreased the environmental impact compared to oat monocropping with N fertilisation. This would improve the nutrient supply to livestock in the mixed farming system, resulting in the enhancement of milk and meat production. Further, this would improve the overall welfare of farmers in mixed farming systems while maintaining the environment. Thus, intercropping oat with field pea is recommended for a more sustainable production of high-quality forage.

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