Turkish Journal of Agriculture - Food Science and Technology, 9(8): 1560-1566, 2021
DOI: https://doi.org/10.24925/turjaf.v9i8.1560-1566.4481

Turkish Journal of Agriculture - Food Science and Technology

Available online, ISSN: 2148-127X | www.agrifoodscience.com | Turkish Science and Technology Publishing (TURSTEP)

Advantages of Grain Legume-Cereal Intercropping in Sustainable Agriculture

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A R T I C L E I N F O

Review Article

Received : 29/05/2021
Accepted : 08/07/2021

Keywords:
Grain legume-cereal intercropping
Sustainable agriculture
Environmental resource use
Efficient N utilization
Cropping system

A B S T R A C T

Sustainable agriculture bases on certain ecological principles in both of crop production and livestocks. Legume-cereal intercropping in sustainable agricultural cropping system is the most applied in the intercropping systems in the World. Legume-cereal intercropping have many benefits such soil conservation, weed control, animal feed and effective land use, greater yield and quality in low-input agricultural system. Land use efficiently is available to evaluate the advantages of intercrop in sustainable agriculture to meet food demand due to increase in population. Amount of N_2 fixed by intercropped legume is less compared to mono crop legume due to competition with cereal. However, proportion of total N derived from fixation (Ndfa %) in legume intercropped with cereal was greater than mono crop legume. N-transfer from the legume to neighbouring plant may be possible, but it can be affected by a lot of factors. The principal aim of present study is to define advantages of cereal-grain legume intercrops in sustainable agriculture.

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Introduction

World faces inreasing human population, also it brings with some problems such as starvation and food security. At the present time, agriculture encounter some problems such as lack of food, soil erosion, excessive use of fertilizers and pesticide, food security (Jackson and Piper, 1989; Bedoussac and Justes, 2011; Raberg et al., 2017). For this reason, crop diversity and crop rotation play important role in agricultural systems. (Hauggaard-Nielsen et al., 2008). Future agriculture needs to demand organic crop without externeous resources. Sustainable agriculture may be part of the solution because it decreases use of synthetic nitrogen (N) fertilizers and it can contribute to soil fertility by use crop rotation. Reganold and Wachter (2016) found that in organic production yield averages are 8 to 25% lower compared with traditional agriculture by using different data in meta-analyses. However, input cost in organic farming is less than in traditional farming (Lampkin and Padel, 1994). Organic farming encompasses sustanability and traditional crop rotation. This what every individual needs to know about benefit natural sciences, because almost all continent exposes global climate change. Due to these rising concern about exploit natural resources and environment pollution, sustainable agriculture its importance is understood. Sustainable agriculture provides food security to generation by means of eco-founctional practice. Intercropping has an important role in sustainable cropping systems**.** Legume-cereal intercrops are the most applied in the intercropping systems in the World. Legume-cereal intercrops have many benefits such soil conservation, weed control, animal feed and effective land use, greater yield and quality in low-input agricultural systems. Intercropping is considerable for increased yield, decreased pest and reduced fertilizer N using (Jensen, 1996a; Jensen et al., 2020).

Intercropping is described as agronomic practice of growing the of two or more species together in the same area and time (Andrews and Kassam, 1976; Ofori and Stern, 1987). Mixed cropping of legumes and cereal is common (Ofori and Stern, 1987; Van Kessel and Hartley, 2000; Jensen et al., 2020) because legumes take place in crop rotation and they can be advantageous following crop. Legumes are fixing nitrogen in the roots by rhizobum. So, N transfer from the legume to non-legume may be affected by a lot of factors and it is very difficult (Jensen, 1996b).

Further legumes contribute to soil improvement, human nutrition and improve of quality forage. However, there are affect many factors of mix crop for example; sowing time of crop, sowing rate, root structure, competitive, interactions between the component species, harvesting time of crop. Designing crop management systems based on crop ability compete with weed, legume to cereal ratio, resource use sharing, root arhitecture allellochemicals (Brisson et al., 2004). Yield of mix crop is advantage than sole crop. Intercropping is an insurance of yields. Besides it increases cereal grain protein content compared to mono crops. Some researchers reported that protein concentration of cereal grain and shoot in legume-cereal intercropping is higher than that of sole crop cereal. (Lithourgidis et al., 2007; Lauk and Lauk, 2008; Jensen et al., 2015). Cereal in intercropping is more competitive for inorganic N than pea (Hauggaard-Nielsen et al., 2008). This reason may be growth root cereals has faster than legumes (Ghaley et al., 2005).

Intercropping boost land equivalent ratio, so in terms of LER intercropping is useful to natural resources as compared to respective sole crops (Yu et al., 2015). The aim of sustainable agriculture was to use efficiently resources for future generation and ecology. Farmers prefer lower input by using especially cereal /legume intercropping. Efficiency of intercrops are available for low nitrogen input farming systems (Willey, 1990; Fukai and Trenbath, 1993; Hauggaard-Nielsen, 2003; David et al., 2005; Desclaux et al., 2008; Bedoussac et al., 2015). In fact, that, protection of natural resources or biodiversity know remarkably important. Legumes take part in sustainability agriculture for major nitrojen source through symbiotic nitrogen fixation. It reduces environmental influence while ensuring sustainability of productivity in modern agriculture (Bedoussac et al., 2015).

The principal aim of this present study was revealed of cereal-grain legume intercrops relationship sustainable agriculture explaining that low input, eco-functional implement, nitrogen use, land equivalent ratio and economic output.

Grain Production Potential of Intercropping

Environmental resources are generally better used by intercrops than sole crop (Neugschwandtner and Kaul, 2014). It can be said that in terms of yield use plant growth factors better by intercrop than the sole crop. Similar observations were informed by some researchers for various systems (Jensen, 1996a; Hauggaard-Nielsen et al., 2008; Bedoussac et al., 2015). There are many factors affected productivity of mix crops such as sowing time of crop, sowing rate, root structure, competitive, interactions between the component species, harvesting time of crop. Competetive abilities of component crops change non-legume and legume root structure. Grain yield of legume-cereal intercrops obtained from various studies were shown in Table 1. Some studies reported that grain yield of sole crop legumes was lower than total grain yield in the intercrops (Haugaard Nielsen et al., 2001; Corre–Hellou et al., 2006; Knudsen et al., 2004; Sarunaite et al., 2010). However, total grain yield in oat-pea intercrops were generally less than in the sole crops (Arlauskiene et al., 2011). Grain yield of pure pea and pure wheat is significantly higher than intercropped components crop without N conditions (Ghaley et al., 2005).

Table 1. Grain yield potential of legume-ceral intercrops and sole crops in different studies.

Country	Sole Crop Legume	Sole Crop Cereal	Legume-Cereal Intercrops
[1]Denmark	pea 2630 kg ha^{-1}	barley 3927 kg ha^{-1}	4577 kg ha^{-1}
[2]Denmark	pea 388-394 g m^{-2} (with N40 and with N5)	barley 210-287 g m^{-2} (with N5 and with N40)	307g m^{-2} (in both cases)
[3]Denmark	pea 268-490 g m^{-2} faba bean 132- 347 g m^{-2} lupin 269- 416 g m^{-2}	barley 211-339 g m^{-2} (sand soil and sandy loam conditions)	231-455 g m^{-2} 207-394 g m^{-2} 220-337 g m^{-2}
[4]Denmark	pea 378-395 g m^{-2} (with N4 and without N)	wheat 127-478 g m^{-2} (without N and with N8)	332-392 g m^{-2} (with N4 and with N8)
[5]France	pea 491g m^{-2}	barley 435g m^{-2}	563 g m $^{-2}$
[6]Lithuania	pea 2368 kg ha^{-1} lupin 1507 kg ha^{-1} bean 1985 kg ha^{-1} vetch 1881 kg ha^{-1} (as mean of three years)	wheat 3146 kg ha^{-1} (as mean of three years)	2930 kg ha^{-1} 2774 kg ha^{-1} 2836 kg ha^{-1} 3338 kg ha^{-1} (as mean of three years)
[7]Lithuania	pea 2936 kg ha^{-1}	wheat 3002 kg ha^{-1} barley 2583 kg ha^{-1} oat 2897 kg ha^{-1} tritikale 2717 kg ha^{-1}	2951 kg ha^{-1} 2750 kg ha^{-1} 2555 kg ha^{-1} 2735 kg ha^{-1}
[8]China	pea 2828 kg ha^{-1} (as mean of three years)	maize 11724 kg ha^{-1} (as mean of three years)	10331 kg ha^{-1} (as mean of three years)
[9]Lithuania	pea 2795-3127 kg ha^{-1} (two location) (as mean of three years)	wheat 2856-3740 kg ha^{-1} triticale 2726-3152 kg ha^{-1} oat 3043-3226 kg ha^{-1} barley 2779-3594 kg ha^{-1} (as mean of three years)	3044-3084 kg ha^{-1} 2853-3432 kg ha^{-1} 2740-3484 kg ha^{-1} 2939-3356 kg ha^{-1} (as mean of three years)

Sources:1: Haugaard Nielsen et.al., 2001; 2: Andersen et al., 2004; 3: Knudsen et al. 2004; 4: Ghaley et al., 2005; 5: Corre –Hellou et al. 2006; 6: Sarunaite et al., 2010; 7: Arlauskiene et al., 2011; 8: Qin et al., 2013; 9: Arlauskiene et al., 2014

Table 2. Effect of different planting pattern on bean and wheat grain in intercropping

Cropping system	B Sole	W Sole	B M1	W M1	B M2	W M2	B M3	W M3
Grain yield (t/ha)	4.85	2.33	4.23	1.01	4.13	1.98	4.21	1.11
HarvestIndex (%)	34.30	30.87	41.02	24.9	41.57	24.25	43.22	25.5
1000- Grain Weight (g)	398.7	39.2	426.85	35.57	431.75	36.22	435.15	37.3

M1: alternate row intercrop; M2: within row intercrop; M3: mixed intercrop B: Bean W: Wheat. Sources: Eskandri and Ghanbari, 2010

Table 3. Land equivalent ratios for grain in the various intercropping in the some studies.

Country	Intercropping	Application	LER
[1]England	pea-oat	different N application	0.85-0.91
[2]Nigeria	cowpea-pearl millet	different periods	1.08-1.43
[3]Yugoslavia	maize-bean	irrigation and rainy conditions	0.93-1.11
[4]Denmark	pea- barley	without N and with 40-50 kg N ha	1.03-1.18
[5]Ethiopia	bean- maize	different N-P applications	0.76-1.41
[6]Ethiopia	faba bean-barley	different mixture rates	1.05-1.21
[7]Poland	pea-barley	different cultivars	1.18-2.01
[8]China	pea- maize-wheat	different components	1.20-1.50
[9]Czech Republic	pea-cereal	different mixture rates	1.04-1.26
[10]Austria	pea-oat	different N and rate	0.79-0.98

Sources: 1: Cowell et al. 1989; 2: Reddy et al., 1992; 3. Oljaca et al. 2000; 4: Hauggard- Nielsen and Jensen, 2001; 5: Abera et al., 2005; 6: Agegnehu et al., 2006; 7: Podgorska- Lesiak and Sobkowicz, 2013; 8: Qin et al., 2013; 9. Hunady and Hochman 2014; 10: Neugschwandther and Kaul, 2014.

The planting systems are one of the most important agronomic applications. Maize with soybean at 10 cm intra spacing increased grain yield (Berdjour et al., 2020). Great soybean yield was provided without affecting maize yield in strip intercropping systems (Du et al., 2018). On the other hand, Eskandri and Ghanbari (2010) indicated that differences among the intercrop planting system were no significant for seed yield of bean and wheat in the intecropping, but grain yield increased in sole crops as compared with intercropped components crops (Table 2).

Role of Intercropping in Weed, Pest and Disease Control

Intercrop yield stabilite depend on weed density, location, ecolological conditions and disease and pest. Weed pressure in legume and cereal intercrops was less than sole crop legume (Hauggaard-Nielsen et al., 2008; Corre-Hellou et al., 2011; Bedoussac et al., 2015). Corre-Hellou et al. (2011) reported that sole crop cereal and intercrop three times advantage compared to pure legume. This reason for this situation intercrop may press weed thanks to alleopathy. Therefore, it might not be suitable organic agriculture, due to excess of weed population sole crop, other benefits of intercrops are lower weed biomass and pest and disease population. Spring sole pea has weed dry matter more than pea- barley intercrop or pea-wheat intercrop or sole barley and sole wheat by Naudin et al. (2009). One of the reasons in intercrop is host plant density. Banik et al. (2006) reported that weed biomass in chickpea-wheat intercrop (20 cm spacing) is lower than about 45% sole crop wheat (20 cm spacing). Components of intercropping can be affected less by pest and disease than mono crops. Intercrops may usefully contribute to the control of pest or disease populations and the decreasing yield loss (Trenbath, 1993).

Legumes (pea, faba bean, lupin)-barley intercrops observed that reduced severity disease by 20% to 40% (Hauggard-Nielsen et al., 2009).

Effective Utilization of Environmental Resources

Yield of intercropping are due to effectively utilization of environmental resources. Substainable agriculture in land use efficiently may be acquire by using mixtures, especially legume/cereal mixtures. Land equivalent ratio (LER) indicates efficiency of intercrops for using the planth growth sources compared with sole crops. Efficient utilization of plant growth factors is useful to evaluate the advantages of intercrop in sustainable agriculture to meet food demand due to increase in population. That is if LER >1 is defined as intercropping more effective for light, water and nitrogen than sole crops (Corre-Hellou et al., 2009; Liu et al., 2018). Hauggaard-Nielsen et al. (2006) found that in both harvest stage land equivalent ratios (LER) values of the intercrops ranged from 1.08 to 1.21. Some researchers showed that various intercrops utilise plant growth factors more effectively %25-50 as compared to sole crop (Hauggaard-Nielsen et al., 2001; Hauggaard-Nielsen et al., 2008). Highest LER was found in maize+soybean double row strips (Üstündağ and Ünay, 2016). Land equivalent ratios for grain in the various intercropping in some studies are exhibited in Table 3. Pea and barley intercropping under low N fertilization condition also used more efficiently environmental sources for plant growth than sole crop (Jensen, 1996a). When applied N fertilization LER<1 for grain was found in pea-oat intercropping (Cowell et al. 1989; Neugschwandther and Kaul, 2014).

Improvement of Forage Yield and Quality

One of the main principles of sustainable agriculture is rising self-sufficiency. Especially livestock farmers may be interested in this principle (Hunady and Hochman, 2014). Actually, sustainable agriculture systems stand out some subject such as ecology, self-sufficiency, economy. In animal nutrition, legume /cereal mixtures provide balance nutrition as well as higher biomass production. Many farmers grow only cereal forage because of low cost. All the same legumes contain protein and fiber for animal husbandry therefore feeding on sole crop cereal is not suitable forage quality (Eskandari et al., 2009). Legume-cereal intercropping give high forage yield and quality for livestocks. Crude protein content and total forage dry matter digestibility of maize and cowpea intercrops increased as compared to mono crops (Dahmardeh et al., 2009). Dry matter yield and quality silage fodder of corn-legumes intercrops were higher than pure stand corn (Geren et al., 2008; Eskandari, 2012). Lithourgidis et al. (2007) reported that common barley-vetch (35-65) intercrops produced higher forage yield and quality than pure vetch crops and other intercrops. On the other hand, sorghum-sudangrass hybrid and legume intercrops gave more hay and protein yield as compared with sole crops (Başaran et al., 2017).

Soil Fertility and Conservation

Legumes and cereal intercrops are considerable for soil conservation and it can be used as cover crop. N is mobilize element, so cover crop can restriction N leaching especially rainy areas. Frasier et al. (2017) found that grass-legume intercrop can restrain N losses and the mixture more efficient in terms of nitrojen use. Sorghum-cowpea intercropping decreased soil loss compared to sole crops (Zougmore et al., 2000). Shallow roots help to reduce soil erosion and intercrops prevent soil loss in the regions with excessive rainfall (Lithourgidis et al., 2011; Dwivedi et al., 2015).

Inorganic nitrogen fertilizer causes environmental damage, so biological nitrogen fixation in legumes is important for sustainable agriculture. Legumes in the intercropping can decompose and benefit subsequent crops (Lithourgidis et al., 2011). Usually, most legumes gather N from biological fixation especially in days to 50% flowering time and days to 100% flowering time. Biological N fixation is substantial source in legume-cereal intercrops in limited nitrogen conditions (Fujita et al., 1992). Legume-maize intercropping improves production and the soil fertility characters for at least three to four years especially at favourable phosphours fertilization (Wang et al., 2014). Mung bean and rice intercropping increases nodulation, nitrogen and phousphorus acquisition in legumes by mycorrhiza formation (Li et al., 2009). Inoculation with mycorrhiza increased transfered N from legume in faba bean- wheat and mung bean-rice intercrops (Li et al., 2009; Ingraffia et al., 2019). Intercrops can increase not only organic C content in soil, but also microbial activity can maintain. Depending on soil C:N ratio and root structure of crops, soil organic decomposes of soil organic matter monocrop slower than intercrop (Cong et al., 2015).

Efficient N Utilization

Symbiotic N_2 fixation is very important for sustainable agricultural systems. Legumes are biological source of nitrogen throughout rhizobium bacteria. Amount of nitrogen fixed by the legumes in legume-cereal intercrops is related to species, density of component crops, root ability and competitive abilities of components (Ofori and Stern, 1987). Nitrogen fixation related on total N acquiremet and proportion of N derived from air or % Ndfa. Although legume is known to be are great resource of nitrojen, many farmers to continue inorganic fertilizers use because of their habit. Ndfa % of legume-cereal intercrops and sole crops in some the studies was exhibited in Table 4. Ndfa % in monocropped legumes had lower than intercropped legumes however it is depending on area, crop diversity (Jensen, 1996a; Corre-Hellou et al., 2006; Andersen et al., 2004; Haugaard Nielsen et al., 2009; Chu et al., 2004). However, Ndfa % in peanut- rice and pea-barley intercrops reduce with increasing inorganic N in soil (Andersen et al., 2004; Chu et al., 2004). Amount of N_2 fixed intercropped pea is less than sole crop pea due to competition with wheat (Hauggaard-Nielsen et al., 2001). However, proportion of total N derived from fixation (Ndfa %) in pea intercropped with cereal was greater than in sole cropped pea without N fertilizer (Ghaley et al., 2005; Hauggaard-Nielsen et al., 2009). On the other hand, there was no significant difference between relative amount of N_2 fixed by pea in intercropping pea with barley or sole cropped pea at the low nitrogen level (Andersen et al., 2005). Fan et al. (2006) reported that Ndfa % increase in wheat-faba bean intercropping compared to maize- faba bean without nitrogen fertilization condition. Plant density affects nitrogen acquisition in intercropping. High biomass and grain nitrogen content of intercropped barley were obtained in higher pea density (Chapagain and Riseman, 2014).

The competition of the cereal is greater than of the legume for uptake of soil N in intercropping (Jensen, 1996a; Ghaley et al., 2005; Dwivedi et al., 2015). In fact, N percentage in grain of intercropped barley was more than mono crop barley (Hauggaard-Nielsen et al., 2001). The highest grain N yield was accumulated in N_0 for sole cropped pea followed by the intercops (Ghaley et al., 2005).

Table 4. Ndfa % in various intercrops and sole crops in some the studies.

Country	Intercrops	Fertilizer	Sole Crop Ndfa %	Intercrop Ndfa %
[1]USA	Cowpea maize	50 DAP (kg ha^{-1}) 80 DAP (kg ha^{-1})	23.6-41.4 dd. of rows 5.8-30.6 dd. of rows	47.9-51.7 dd. of rows 34.4-44.2 dd. of rows
[2]Denmark	pea- barley	50 kg N ha^{-1}	45.0-62.0 dp.	73.0-82.0 dp.
[3]Denmark	pea-barley	0.5 g N m^{-2} 4 g N m^{-2}	58.0-79.0 dp. 61.0-88.0 dp.	81.0-87.0 dp. 76.0-85.0 dp.
[4]China	peanut-rice	15 kg N ha^{-1} 75 kg N ha^{-1} 150 kg N ha^{-1}	72.8 56.5 35.4	76.1 53.3 50.7
[5]France	pea -barley	0-30-130 kg N ha^{-1}	64.6	75.9
[6]Denmark, United Kingdom, France, Germany Italy	pea- barley	Organic cropping system	66.4	72.9-73.4 dmr.

Sources: 1: Van Kessel and Roskoski, 1988; 2: Jensen 1996a; 3: Andersen et al., 2004; 4: Chu et al., 2004; 5: Corre-Hellou et al. 2006; 6: Haugaard Nielsen et.al., 2009. dd: different distances, dp: different period, dmr: different mixture rate

Intercrops show that grain protein concentration of cereal increase compared with sole crop (Pelzer et al., 2016). Grain N contentration in cereal combined with legume higher than sole cereal but it is depending on cultivar and soil conditions. Hauggaard-Nielsen et al. (2008) showed that grain N concentration of sole crop barley is 1.43% in sandy soil while grain N concentration of barley-pea intercrop is 1.80% in sandy loam soil. Protein content (11.1%) in grain of intercropped cereal was higher as compared with cereal monocrop (9.8%), but difference between intercropped legume and sole cropped legume is not significant for protein content in grain (Bedoussac et al., 2015). Similarly, Neumann et al. (2007) reported that nitrogen conceration in grain of intercropped pea and oat in the intercropping as compared with sole crops in both of conventional and minumum tillage systems.

N-transfer from the legume to non-legume plant may be possibble, but it can be affected by a lot of factors and it is very difficult (Jensen, 1996b). Therefore, amount of transferred N to non-legume may be smaller in cereal than amount of N taken up from other resources (Jensen, 1996a).

Conclusions

Sustainable agriculture provides food security to generation by means of eco-founctional practice. Intercropping has an important role in sustainable cropping systems**.** Legume-cereal intercrops are the most applied in to the intercropping systems in the World and it has many benefits such soil conservation, improvement of soil fertility, weed control, animal feed and efective land use, greater yield and quality in low–input agricultural system. Legume-cereal intercropping for great biomass and grain production must be grown in low-input agriculture. Yield of intercropping are due to effectively utilization of environmental resources. N content in grain of intercropped cereal increases compared to sole crop. Legume and cereal intercropping under low N fertilization condition also used more efficiently for plant growth sources such as for light, water and nitrogen.

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