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SMALL GRAIN CEREAL–CLOVER MIXTURES FOR FORAGE PRODUCTION

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ABSTRACT. Fresh forages are the cheapest source of animal feed in world. Small grain cereals (SGC) are the most commonly used fresh forages or ensiled forage. Clovers are the perennial legumes that offer quality forage but their initial dry matter (DM) yield is low. Usually, SGC and clover are sown in mixtures to draw benefits from greater Cut-1 DM yield of cereals and biological nitrogen (N) fixation of clovers. However, mixtures are difficult to manage, compared to monoculture owing to differences in their growth pattern, temporal, spatial and physical requirements. In this review, SGC-clover mixtures are analyzed for their potential herbage DM yield and quality of the produce. Effect of various management factors on the productivity of forage mixtures are well documented. Decisions in managing mixtures, like choice of cereal and cutting time and how they affect the value of the final produce is reviewed. Besides decision, effect of relative proportion and spatial arrangement of intercrops is also deliberated. Special attention is paid to the competition between SGC and clovers and its impact on clover suppression in mixture. At the end conclusions are drawn to optimize production from mixtures.

Keywords: clover regrowth; competition; cutting time; relative proportion; spatial arrangement.

INTRODUCTION

Intercropping is aimed at higher crop productivity besides other associated advantages, i.e. greater yield stability between different and diverse climatic conditions (Deak *et al.*, 2009), lower incidence of pests, higher nutritional value of mixed diets, improved water use efficiency, yield advantage in subsequent crops,

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reduced soil erosion because of greater ground cover and higher land use efficiency (Anil *et al*., 1998). Mixed cropping is based on the ecological principle of biodiversity and is assumed to have potential benefits in productivity, resilience to disruption and ecological sustainability (Vandermeer, 1989).

Mixture of small grain cereals, the name given owing to their short plant structure, like wheat, oat, barley, rye and triticale with clovers have been exploited in many areas of the world. This mixed sowing system is advocated for its potential of providing shield against high production cost along with better distribution of labor and equipment. Foremost objective in sowing cereal-clover mixture for forage is to have higher green/DM yields of better quality as a result of clover inclusion. Proposed benefits from this mix sowing arise from differences of both species in plant phenology, growth habit, root system and exploitation of different soil depths for nutrients.

Apart from yield and quality advantages, cereal-clover mixtures provide forage throughout the season. This aspect of cereal-clover mixture lie with the clover's potential of multiple cuttings, especially when climate and moisture dynamics prolong the growing season and exceeds cutting date of cereal in mixture. First cut in SGC-clover system with bulk of cereal share may be preserved as silage while subsequent cuts of clover be used as fresh forage (Ross *et al*. 2004a).

Theories and approaches in mixtures greatly differ from that of monocultures (Ross *et al*., 2004a), as both of the intercrops in SGC-Clover mixtures interact with each other on time and space scale. Most of the agronomic practices aimed at optimizing tradeoffs between DM yield and forage quality. However, success of this intercropping system depends upon many factors like species of intercrops, relative seeding proportions, cutting time (Eskandari *et al*., 2009), spatial arrangements and period of their co-existence etc.

Literature reticence on the subject urged the authors to review diffused literature to concisely amass salient outcomes of different studies addressing various management aspects of mixtures. In this review, productivity is discussed in view of DM production and forage quality improvement. Role of cereal choice in success of mixture and cutting time of the mixtures are also deliberated. This article further highlights the dynamics of interaction between SGC and clover and its potential impact on final produce.

Choice of cereal

Selection of suitable SGC to mix with clover is very crucial in the success of intercropping system as choice of cereal affects the performance of intercrop in mixture (Ross *et al*., 2004a,b). Cereals vary for growth habit, tolerance to stress, morphology of leaves and roots, biomass accumulation pattern, intrinsic yield ability and nutritional value (Collins and Rhodes, 1990), which provide the option for the farmers to select the cereal crop to meet their own objectives. A general comparison of small grain cereals are depicted in *Table 1* (adapted from Braunwart *et al*., 2001).

Table 1 - A character comparison of small grain cereals (number of stars indicate character strength of the cereal)

Cereal	Early growth	High grain yield	Tolerance to disease	Tolerance to sodic soil	Tolerance to drought
Wheat	**	***	***	**	**
Rye	****	*	****	***	****
Oat	***	*	*	*	*
Barley	****	**	*	***	***

A compatible cereal-legume mixture assures clover contents in mixture large enough to optimize the potential benefits of N-fixation and mixture quality improvement (Rhodes *et al.*, 1994). Even the cereal cultivars have differences in their effects on clover stand, clover yield and total biomass production (Holland and Brummer, 1999). Semi-dwarf or short stature cultivars are more suitable for mixing with berseem clovers due to less lodging, compared to conventional-stature cultivars (Simmons *et al*., 1995) and offers less competition to companion crop (Simmons *et al*., 1995; Ross *et al*., 2004a,b). Barley is more competitive than other cereals and if a more competitive cereal is to be used then fertilizer rate should be kept low as higher fertilizer rate tends to increase competitive ability of cereals (Annicchiarico and Tomasoni, 2010) and lower the N fixation of clovers (Hogh-Jensen and Schjoerring, 1997).

Earlier maturity of cereal provides longer regrowth periods for clover, that provides higher regrowth (Ross *et al*., 2004b). Barley reaches to its heading and subsequent growth stages earlier than oat, wheat and ryegrass and produce greater DM yield (Ross *et al*., 2003; Ross *et al*., 2004a; Contreras-Govea and Albrecht, 2005). However, inclusion of early maturing cereal (barley) in mixture with clover reduces the initial forage yield of mixture, compared to late maturing cereal like oat (Ross *et al*., 2004a; Thompson *et al*., 1992; Juskiw *et al*., 2000). In situations where objective is to have higher Cut-1 DM yields oat-clover mixture should be the choice as it yields greater Cut-1 DM yield than barley-clover (Jedel and Salmon, 1994; Ross *et al*., 2004b) and ryegrass-clover (Wickham *et al.,* 2007) mixtures owing to more tiller mean weight and taller oat plants (Ross *et al*., 2004a). However, considering total seasonal production, barley-clover mixture is more advantageous owing to early maturity that provides more regrowth period for clover and higher CP contents of barley, compared to other cereals.

Dry matter production

Cereals yield more than clover monocultures and cereal-clover binary mixtures prior to Cut-1 (Contreras-Govea and Albrecht, 2005; Ross *et al*., 2005a; Shoaib *et al*., 2013; Andrzejewska *et al*., 2014), yet some researchers found that mixtures yields equal or greater DM yield than component sole corps (Vasilakoglou and Dhima, 2008; Salama, 2015). However, total seasonal DM production from SGC-clover mixture exceeds both cereal and legume monocultures due to cereal contribution in Cut-1 and subsequent multiple cutting of clover (Shoaib *et al*., 2013; Andrzejewska *et al*., 2014). Cereals dominate early season DM while clover provides the production stability in mixture (Matusinsky and Hrabe, 2003) and improves the forage quality (Ross *et al*., 2005 a,b). There is a negative relationship between Cut-1 cereal herbage DM yield and regrowth clover herbage DM yield (Holland and Brummer, 1999; Ross *et al*., 2004b).

Slow establishment of clover is one of the reasons of its negligible Cut-1 DM yield in mixture with cereals (Ross *et al*., 2005 a,b). According to Martiniello (1999), average legume % in the mixtures of clovers (berseem, crimson and persian) with barley and Italian ryegrass was 22 and 21%, respectively. Similarly, Ross *et al*. (2005b) found berseem % in mixture with oat to be 21-43% under varying seeding ratios of oat. In Faisalabad conditions, berseem % in mixture with 25% oat seeding ratio was 16.94% and 13.70% of total Cut-1 DM yield at booting and heading stage of oat, respectively (Shoaib *et al*., 2013). However, efforts should be made to maximize the clover contents in Cut-1 DM yield as high as 30% (Thomas, 1992).

Nitrogen management is very critical in success of cereal-clover forage mixture as N subsidy to cereal by N fixation of clover fix the adverse effect of some soil nutrient deficiency contributing towards higher production (Matusinsky and Hrabe, 2003). However, mixtures fertilized with N would tend to favour the growth of cereal component and hence more DM yield is expected (Anil *et al*., 1998). Therefore, if objective is to have a handful of clover % in Cut-1 then N application should be low. Environment also plays a key role in the productivity of binary mixtures. Season with more rainfall and soils with more minerals is likely to yield higher herbage DM yields (Vasilakoglou and Dhima, 2008; Campillo *et al*., 2005).

Forage quality

Cereals are nutritionally inferior forage stuff owing to its lower protein and higher fibrous contents. Furthermore, decline in CP concentrations with maturity in cereal is more rapid than clovers (Khorasani *et al*., 1997; Ross *et al*., 2005a). However, animal feed consisting of only clovers can cause bone abnormalities in animals due to incorrect ratio of Ca and P and cereal in mixture helps in correcting the Ca and P ratio and lower the bloating incidence in animals (Hall *et al*., 1991). Inclusion of clover in cereal forage production system will not only lower the cost of production by replacing N fertilizers but also improve the quality of forage resulting in increased intake and digestibility of the forage (Ross *et al*., 2005a; Butler *et al*., 2012). Cereals have higher concentrations of neutral detergent fiber (NDF) and acid detergent fiber (ADF), compared to legumes (Moore and Jung, 2001); therefore, clovers can lower the fiber contents of the mixture. For instance, Sleugh *et al*. (2000) and Ross *et al.* (2005a) observed 30% and 30 g kg^{-1} DM decrease in NDF concentration in wheat-kura clover and oat-berseem mixtures, compared to sole cereal component, respectively, that is indicative of increased intake. A SGC-clover mixture also minimize the N losses owing to cereal uptake of mineral N from soil and slower rate of N mineralization on decomposition (Azo *et al*., 2012). Though sole clover could have higher CP concentrations, but CP yield ha^{-1} would generally be higher in cereal-clover mixtures (Shoaib *et al*., 2013) as CP ha^{-1} largely depends on DM production (Eskandari *et al*., 2009). Better quality forage from SGC-C mixture is mainly due to two reasons: firstly, due to the transfer of fixed nitrogen by clover to the cereal companion in mixture during growth, and secondly, due to the legume presence in harvested forage. Therefore, to witness the improvement in forage quality through clover inclusion, some handful proportion of clover in the mixture has to be assured. Nutritive value of clover regrowth is not much affected by presence of cereal prior to Cut-1 however, cereal regrowth can lower the forage quality of regrowth cut (Andrzejewska *et al*., 2014).

In mixtures, cereals are more efficient in absorbing soil N, compared to clovers, due to their differential abilities in depleting soil N resources (Munoz and Weaver, 1999) hence clovers have to depend on symbiotic nitrogen fixation for their N needs in mixture (Giambalvo *et al*., 2011; Vinther, 2006). Co-existence of legume and cereal roots in soil increase the likelihood of N transfer from legume to cereal through soil solution (Paynel and Cliquet, 2003; Giambalvo, 2011). Chances of N transfer from legume to companion crop are more when their roots interact within the proximity of 0.5 mm of root exudates (Zhang *et al*., 2004). Furthermore, SGC compared to dicotyledonous have greater chances of receiving N from legumes owing to their fibrous root system (Pirhofer-Walzl *et al*., 2012). In their study, Dahlin and Stenberg (2010) assessed that nitrogen transfer from clovers to grass made up 30-57% of grass nitrogen.

Legume species differ in their ability to transfer fixed N to companion grass (Louarn *et al*., 2015). Pirhofer-Walzl *et al*. (2012) reported that white clover, red clover and alfalfa (closely related genera to *Trifolium*) approximately transferred 9 kg N ha^{-1} to *Festulolium* and ryegrass roots. However, in their study, Ledgard (1991) found that amount of N transferred from white clover to ryegrass was 54 to 102 kg N ha^{-1}. In some other studies, amount of N transferred was 36 kg from red clover to perennial ryegrass (Dahlin and Stenberg, 2010), while from white clover to ryegrass was 49.5 kg ha^{-1}. Contrarily, certain scientist found no apparent fixed N transfer from clover to ryegrass (McNeill and Wood, 1990; Giambalvo, 2011). Among the clovers, white clovers is more efficient N donor species, compared to other clovers and match well with grasses in terms of sustainable N supply (Pirhofer-Walzl *et al*., 2012: Høgh-Jensen and Schjoerring, 2001), that could be attributed to higher proportion of fine roots with lower C:N ratio resulting in more rapid release of N (Louarn *et al*., 2015).

Among other nutrients, berseem clover increased Mn influx to oat and ryegrass by a factor of four in mixture (Arneja and Sadana 2012). In multi-layer rooting system found in mixed cropping systems, subsoil K sources are effectively utilized (Ehrmann and Ritz, 2014). In ryegrass-clover mixture system, subsoil K uptake was up to 55% (Witter and Johansson, 2001). In conclusion, quality of mixed forage is improved by in-season N transfer from clover to cereal, presence of clover in harvested stuff, influx of other nutrients to cereals and greater exploitation of subsoil minerals.

Competition and clover suppression

When two crops are sown in same field, competition among them may occur (Vandermeer, 1989), that may affect survival, growth and reproduction of at least one of the species in mixture (Crawley, 1997). However, competitive relationship among mixture components can be manipulated to maximize the productivity of mixture (Giambalvo *et al*. 2011). Objectives of research into SGC-clover mixtures is to explore intraspecific relations and their harmonization as a factor of agreement between forage production and quality (Matusinsky and Hrabe, 2003). Zhang and Li (2003) proposed a competition-recovery production principle for long duration-short duration intercrops co-existing intercropping system, according to which, interspecific competition favors growth, nutrient uptake and yield increase of dominant species but inversely effects the subordinate species. However, after the harvest of dominant species the sub ordinate species recovers so that final yield is maintained or enhanced.

In SGC-clover mixtures, many factors favors cereal growth during the time of their co-existence. Some of the factors that contribute to competitive advantage to cereals are plant height (Korres and Froud-Williams, 2002), early plant/canopy establishment, and high growth rate (Ross *et al*., 2005a). In addition, cereals are more productive than clovers in relation to unit amount of N accumulated owing to photosynthates being respired by legumes for N fixing (Osaki, 1994). Plant height is an important factor in competitiveness of crop (Lemerle *et al*., 2001; Mason *et al*., 2007; Zerner *et al*., 2008). Taller plants, generally, have most of their leaves higher in canopy that help in more light interception and suppression of small plants due to shading. According to Ross *et al*. (2004a), PAR available to berseem in barley-berseem and oat-berseem mixture was 33% and 47%, respectively.

Early plant vigor is highly associated to its competitive ability (Lemerle *et al*., 2001). Early plant establishment and reduced time to maturity improves the crop response to competitor in vicinity (Mason *et al*., 2007). While evaluating oat-berseem mixture for forage under varying oat densities, Ross *et al*. (2005a) observed maximum LAI ranging from 7.3-7.6 at 65-66 days after planting, when they used 240 seeds m^{-2}, while range was 5.6-5.7 at 60 seeds m^{-2}. This early canopy development of cereals than berseem caused considerable shading to the berseem plants, that are at lower layer of canopy (Ross *et al*., 2005a).

Root exudates of oat and Italian ryegrass have been reported to contain various toxic substances, that can effect seedling growth of companion clover (Iannucci, 2006). Clover suppression by cereals is also traced in alellopathic effect of exudates from live roots of forage cereals on root length and early seedling development of clover (Iannucci, 2006). However, more research work is warranted to find out effectiveness of this phenomena for various SGC-clover mixtures under field conditions.

Research into the small grain cereal-clover mixture suggested that yield optimization could be achieved by the mixtures, but same time cereal imposes a severe competition on clover component, that is reflected by poor proportion of clover in produce and less clover persistence. Relatively early emergence of clover, reduction of competition from cereal, early timing of Cut-1, adequate soil moisture, and a lengthy period of regrowth can promote the clover proportion in cereal-clover mixture (Ross *et al*., 2005b).

Effect of relative proportion

Relative proportion of intercrops is an important factor affecting competitive ability of crops and forage production in mixture (Vinther, 2006). Optimum plant densities of small grain cereals and clovers monocultures determined for different regions are of little or no value in predicting their relative densities in their binary mixtures (Bulson *et al*., 1997). Changes in the sowing rate of dominant species, i.e. cereals, have greater effect on species composition and Cut-1 herbage DM yields

(Ross *et al*., 2003; Ross *et al*., 2005b; Vasilakoglou and Dhima, 2008). Increased seeding rates of cereal favors early season ground cover and DM accumulation however final DM yield is unaffected of the seeding rates (Brennan *et al*., 2009). Productivity of mixtures are enhanced when cereal densities are kept low mainly due to less competition to clover prior to Cut-1 that will translate into higher clover regrowth subsequently (Ross *et al*., 2005b: Shoaib *et al*., 2013). Less plant densities of cereals in mixtures make available more soil N to cereals, compared to monoculture and this complementarity effect can partly explain cereal dominance in mixture (Schipanski and Drinkwater, 2012; Louarn *et al*., 2015). On the other hand, less clover density will lead to lower amount of atmospheric derivated N (Neumann *et al*., 2007). However, in presence of competitively superior companion, impact of higher clover seeding rate would be little early in the season (Ross *et al*., 2004a).

Cutting management

Some important growth stages of small grain cereals are defined below (adapted from Collar and Aksland, 2001).

- Boot: Just prior to heading (appearance of grain head or spike), with the flag leaf (top most leaf) fully expanded. The grain head is not yet visible, but can be felt near the top of the plant inside the sheath of the flag leaf.
- Heading: Grain head (spike) emerges from the sheath of the flag leaf.
- Flower: Grain head and supporting stem have fully emerged from the sheath of the flag leaf; anthers have emerged from the grain head and are shedding pollen.
- Milk: Grain kernels are developing and are filled with a white, milky liquid.
- Soft dough: Grain kernels are well formed and have the consistency of a rubbery dough.

Cutting management in forage mixture could be used to manipulate the pattern of seasonal yield and aids in temporal complementarity (Ross *et al*., 2005b). Herbage DM contents in cereals increase with advanced maturity (Khorasni *et al.,* 1997). Decrease in feeding value of forages with advanced maturity is due to physio-chemical changes in plants (Vranic *et al*., 2009). In plants, CP contents decrease while ratio of cell wall contents increase with maturity that reduce the forage intake and digestibility of forages (Jancik *et al*., 2008; Azo *et al*., 2012), which has a practical significance. Cutting the forage too late limits the animal growth by low N contents (Kaiser *et al*., 2007), while forages cut at early stages have poor N capture efficiency in the rumen (Aibibula *et al*. 2007). However, Andrzejewska *et al*. (2014) is of the view that cutting time of the cereal-clover mixture would not affect the second or third cut clover regrowth yield. Contrarily, time of the Cut-1 will influence the regrowth of cereal. In oat/rye/triticale-clover mixtures, cereals deprived of regrowth, when harvested at early heading stage (Shoaib *et al*., 2013; Andrzejewska *et al*., 2014), which may be attributed to decrease in number of tillers capable of regrowth with delayed cutting (Ross *et al*., 2005b).

According to Khorasani *et al*. (1997), DM concentration is almost similar in all small grain cereals up to booting stage. Similarly, almost all the small grain cereals have the same pattern of DM accumulation and maturation, nevertheless varieties may differ in onset of different growth stages (Fohner, 2002). In SGC-clover mixtures, cutting largely depends on the growth stage of the associated cereal because of the higher contribution from cereal in DM production (Shoaib *et al*., 2013).

Regrowth of clovers

Seeding rate of cereal in sowing mixture has a key effect on clover regrowth yields (Ross *et al*. 2005b; Contreras-Govea and Albrecht, 2005). Contreras-Govea and Albrecht (2005) observed on average 0.8 Mg ha^{-1} yield reduction at first regrowth from SGC-kura clover, compared to kura clover monoculture. According to Ross *et al*. (2005b) lower berseem regrowth yield in oat-berseem mixture, compared to berseem monoculture was due to lesser residual leaf area after Cut-1 as regrowth of annual clovers depends upon residual leaf area and rapid leaf generation rather than stored food (Kendall and Stringer, 1985). Furthermore, lack of space for berseem to establish at early growth stage reduced its regrowth ability (Ross *et al*., 2005b). Nonetheless, clovers have excellent ability to recover from stress imposed by cereal prior to Cut-1 and produce almost similar total seasonal yield to clover monoculture in their regrowth phase (Shoaib *et al*., 2013; Andrzejewska, 2014). According to Giambalvo *et al*. (2011), berseem has greater capacity to recover after defoliation, compared to other clovers and frequent cuttings of berseem make it more competitive. This is why, cereal dominates mixtures prior to Cut-1, while clover dominates during regrowth phases (Ross *et al*., 2005b).

Spatial arrangements

Temporal complementarity is more likely to have higher yield advantage in intercropping system than spatial complementarity (Willey, 1979). However, spatial complementarity for SGC-clover is equally important as some minimum space is required for clover to establish (Ross *et al*., 2005b). Without an initial space for clover, its regrowth yield reduced in spite of temporal facilitation (Ross *et al*., 2005b).

Intercrops in mixtures arranged to achieve planting uniformity are more probable to increase productivity (Olsen *et al*., 2005), that could be better achieved in row planting. One way to achieve planting uniformity is to plant intercrops in grid pattern, but this method involves extensive tractor use that will increase soil compaction and expenses on fuel, labor and machinery maintenance (Brennen *et al*., 2009). In their study, Giambalvo *et al*. (2011) achieved higher DM yields in berseem-ryegrass mixture from alternative rows, compared to same row (mixed seed sowing). Wider row spaces of cereals in mixture would benefit clover component and will assure handful proportion in mixture (Annicchiarico and Tomasoni, 2010).

Planting arrangement is also a key factor in N transfer from clover component to cereal component. Chances of effective N transfer increase when root systems of both component are in proximity (Giambalvo *et al*., 2011). However, reducing the intimacy of the components of cereal-legume mixture will benefit less competitive component of the mixture (Annicchiarico and Tomasoni, 2010; Giambalvo *et al*., 2011). Therefore, decision regarding planting arrangement could be done on base of type of species in mixtures and to achieve uniformity among intercrops.

CONCLUSIONS

Complexity in the growth, interactions and the conditions in which mixtures sown is not suitable to draw general conclusions, but some comments can be made about the said mixture. Early maturing and short stature cereals or their cultivars are more suitable to mix with clovers. Efforts should be made to maximize the clover contents in Cut-1 DM yield as high as 30%, which may be achieved by selecting a more competitive clover species or identification of less competitive cereal component. Presence of clovers and below ground nutrient facilitation enhance the forage nutritive value of mixture. To assure good Cut-1 DM yield and vigorous clover regrowth, cereal seed proportion should be kept low to minimize competition. Cutting time of the mixture should not be later than heading stage of cereals as at this stage DM yield and forage quality is in compromise, while delaying the cutting will deteriorate the quality of mixture and decrease clover regrowth potential. Maintaining uniformity between intercrops is more likely to achieve greater productivity. Decreasing the proximity between cereals and clover (wider row spaces) would yield higher DM yields, but lower N uptake by cereal. Certain management factors of SGC-clover mixtures are not discussed in this review to keep it in reasonable size. However, a future review should also discuss fertilizer, weed and irrigation management of various SGC-clover mixtures. Moreover, role of allelochemicals in mutual interaction of SGC-clover is yet to explore.

REFERENCES

Aibibula Y., Okine A., Hanada M., Murata S., Okamoto M., Goto M., 2007 - Effect of replacing rolled corn with potato pulp silage in grass silage-based diets on nitrogen utilization by steers. Asian-Australas. J. Anim. Sci., 20(8):1215-1221.

Andrzejewska J., Albrecht K.A., Harasimowicz-Hermann G., 2014 - Intercropping winter cereals with Caucasian clover for forage in northern Europe. Acta Agric. Scand., Sect. B Soil Plant Sci., 64:734-740.

Anil L., Park J., Phipps R.H., Miller F.A., 1998 - Temperate intercropping of cereals for forages: a review of the potential for growth and utilization with particular reference to the UK. Grass Forage Sci., 53(4):301-317.

Annicchiarico P., Tomasoni C., 2010 - Optimizing legume content and forage yield of mown white clover-Italian ryegrass mixtures through nitrogen fertilization and grass row spacing. Grass Forage Sci., 65(2):220-226.

Arneja A., Sadana U.S., 2012 - Mixed cropping effects on yield, manganese influx, and manganese depletion in the rhizosphere of fodder crops grown in manganese-deficient soil. Commun. Soil Sci. Plant Anal., 43(3):533-540.

Azo W.M., Lane G.P.F, Davies W.P., Cannon N.D., 2012 - Bi-cropping white lupins (*Lupinus albus* L.) with cereals for wholecrop forage in organic farming: The effect of seed rate and harvest dates on crop yield and quality. Biol. Agric. Hortic.: An International Journal for Sustainable Production Systems, 28(2):86-100.

Braunwart K., Putnam D.H., Fohner G., 2001 - Alternative annual forages - now and in the future. *In:* Proceedings, 31st California Alfalfa and Forage Symposium, 12-13 Dec., 2001, Modesto, CA, Department of Agronomy and Range Science, UC Davis.

Brennan E.B., Boyd N.S., Smith R.F., Foster P., 2009 - Seeding rate and planting arrangement effects on growth and weed suppression of a legume-oat cover crop for organic vegetable systems. Agron. J., 101(4):979-988.

Bulson H.A.J., Snaydon R.W., Stopes C.E., 1997 - Effects of plant density on intercropped wheat and field beans in an organic farming system. J. Agr. Sci., 128:59-71.

Butler T.J., Muir J.P., Huo C., Guretzky J., 2012 - Switchgrass biomass and nitrogen yield with over-seeded cool-season forages in the Southern Great Plains. Bioenerg. Res., 6(1):44-52.

Campillo R., Urquiaga S., Undurraga P., Pino I., Boddey R.M., 2005 - Strategies to optimize biological nitrogen fixation in legume/grass pastures in the southern region of Chile. Plant Soil., 273(1): 57-67.

Collar C., Aksland G., 2001 - Harvest stage effects on yield and quality of winter forage. *In:* 31stCalifornia Alfalfa Symposium. University of California Cooperative Extension. University of California, Davis.

Collins R.P., Rhodes I., 1990 - The basis and significance of compatibility in grass/clover mixtures. Herba, 3:30-32.

Contreras-Govea F.E., Albrecht K.A., 2005 - Mixtures of kura clover with small grains or Italian ryegrass to extend the forage production season in the Northern USA. Agron. J., 97:131-136.

Crawley M.J., 1997 - Plant ecology. Blackwell, Scientific, Cambridge.

Dahlin A.S., Stenberg M., 2010 - Transfer of N from red clover to perennial ryegrass in mixed stands under different cutting strategies. Eur. J. Agron., 33:149-156.

Deak A., Hall M.H., Sanderson M.A., 2009 - Grazing schedule effect on forage production and nutritive value of diverse forage mixtures. Agron. J., 101:408-414.

Ehrmann J., Ritz K., 2014 - Plant: soil interactions in temperate multi-cropping production systems. Plant Soil, 376:1-29.

Eskandari H., Ghanbari A., Javanmard A., 2009 - Intercropping of cereals and legumes for forage production. Not. Sci. Biol., 1(1):7-13.

Fohner G., 2002 - Harvesting maximum value from small grain cereal forages. *In:* Proceedings, Western Alfalfa and Forage Conference, 11-13 Dec., 2002, Sparks, NV, UC Cooperative Extension, Univ. of California, Davis (See http://alfalfa.ucdavis.edu).

Giambalvo D., Ruisi P., Di Miceli G., Frenda A.S., Amato G., 2011 - Forage production, N uptake, N_2 fixation and N recovery of berseem clover grown in pure stand and in mixture with annual ryegrass under different managements. Plant Soil, 342(1):379-391.

Hall D.D., Cromwell G.L., Stahly T.S., 1991 - Effects of dietary calcium, phosphorus, calcium: phosphorus ratio and vitamin K on performance, bone strength and blood clotting status of pigs. J. Anim. Sci., 69(2):646-655.

Høgh-Jensen H., Schjoerring J.K., 1997 - Interactions between white clover and ryegrass under contrasting nitrogen availability: N_2 fixation, N fertilizer recovery, N transfer and water use efficiency. Plant Soil, 197(2):187-199.

Høgh-Jensen H., Schjoerring J.K., 2001 - Rhizodeposition of nitrogen by red clover, white clover and ryegrass leys. Soil Biol.Biochem., 33:439-448.

Holland J.B., Brummer E.C., 1999 - Cultivar effects on oat-berseem clover intercrops. Agron. J., 91:321-329.

Iannucci A., 2006 - Evidence of chemical interactions on germination and seedling growth in annual forage species. Journal of New Seeds, 8:1-13.

Jancik F., Homolka P., Čermák B., Lád F., 2008 - Determination of indigestible neutral detergent fibre contents of grasses and its prediction from chemical composition. Czech J. Anim. Sci., 53: 128-135.

Jedel P.E., Salmon D.F., 1994 - Forage potential of Wapiti triticale mixtures in central Alberta. Can. J. Plant Sci., 74(3):515-519.

Juskiw P.E., Helm J.H., Salmon D.F., 2000 - Competitive ability in mixtures of small grain cereals. Crop Sci., 40:159-164.

Kaiser A.G., Dear B.S., Morris S.G. 2007 - An evaluation of the yield and quality of oat-legume and ryegrass-legume mixtures and legume monocultures harvested at three stages of growth for silage. Aust. J. Exp. Agric., 47(1):25-38.

Kendall W.A., Stringer,W.C., 1985 - Physiological aspects of clover. *In:* Taylor N.L. (Ed.) Clover Science and Technology, 111-159. Madison, WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

Khorasani G.R., Jedel P.E, Helm J.H., Kennelly,J.J., 1997 - Influence of stage of maturity on yield components and chemical composition of cereal grain silages. Can. J. Anim. Sci., 77:259-267.

Korres N.E, Froud-Williams R.J., 2002 - Effects of winter wheat cultivars and seed rate on the biological characteristics of naturally occurring weed flora. Weed Res., 42: 417-428.

Ledgard S.F., 1991 - Transfer of fixed nitrogen from white clover to associated grasses in swards grazed by dairy cows, estimated using 15N methods. Plant Soil, 131: 215-223.

Lemerle D., Gill G.S., Murphy C.E, Walker S.R, Cousens R.D., Mokhtari S., Peltzer S. J., Coleman J., Luckett D.J., 2001 - Genetic improvement and agronomy for enhanced wheat competitiveness with weeds. Aust. J. Agric. Res., 52:527-548.

Louarn G., Pereira-Lopès E., Fustec J., Mary B., Voisin A.S, Carvalho P.C. de F., Gastal F., 2015 - The amounts and dynamics of nitrogen transfer to grasses differ in alfalfa and white clover-based grass-legume mixtures as a result of rooting strategies and rhizodeposits quality. Plant Soil, 389:289-305.

Martiniello P.,1999 - Effects of irrigation and harvest management on dry matter yield and seed yield of annual clovers grown in pure stand and in mixtures with graminaceous species in a Mediterranean environment. Grass Forage Sci., 54:52-61.

Mason H., Navabi A., Frick B., O'Donovan J., Spaner,D., 2007 - Cultivar and seeding rate effects on the competitive ability of spring cereals grown under organic production in Northern Canada. Agron. J., 99:1199-1207.

Matusinsky P., Hrabe F., 2003 - Dynamics of stand composition changes in grass and grass-clover stands and relations between dominant species. Plant Soil Environ., 49:119-125

McNeill A.M., Wood M., 1990 - Fixation and transfer of nitrogen by white clover to ryegrass. Soil Use Manage., 6: 84-86.

Moore K.J., Jung G.H., 2001 - Lignin and fiber digestion. J. Range Manage., 54: 420-430.

Munoz A.E., Weaver R.W., 1999 - Competition between subterranean clover and ryegrass for uptake of ^{15}N-labeled fertilizer. Plant Soil, 211:173-178

Neumann A., Schmidtke K. Rauber R., 2007 - Effects of crop density and tillage system on grain yield and N uptake from soil and atmosphere of sole and intercropped pea and oat. Field Crops Res., 100: 285-293.

Olsen J., Kristensen L., Weiner J., 2005 - Effects of density and spatial pattern of winter wheat on suppression of different weed species. Weed Sci., 53:690-694.

Osaki M., 1994 - Differences in carbon and nitrogen utilization between cereals and legumes. *In:* Roots and nitrogen in cropping systems of the semi-arid tropics. O. Ito, C. Johansen, J.J. Adu-Gyamfi, K. Katayama, J.V.D.K. Kumar Rao, T.J. Rego (Eds.). Proceedings of the International Workshop: Dynamics of Roots and Nitrogen in Cropping Systems of the Semi-Arid Tropics,International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, Nov. 21-25.

Paynel F., Cliquet J., 2003 - N transfer from white clover to perennial ryegrass, *via* exudation of nitrogenous compounds. Agronomie, EDP Sciences, 23:503-510.

Pirhofer-Walzl K., Rasmussen J., Høgh-Jensen H,, Eriksen J., Søegaard K., Rasmussen J., 2012 - Nitrogen transfer from forage legumes to nine neighbouring plants in a multi-species grassland. Plant Soil, 350(1):71-84.

Rhodes I., Collins R.P., Evans D.R., 1994 - Breeding white clover for tolerance to low temperature and grazing stress. Euphytica, 77(3):239-242.

Ross S.M., King J.R., O'Donovan J.T., Izaurralde R.C., 2003 - Seeding rate effects on oat-berseem clover intercrops. Can. J. Plant Sci., 83:769-778.

Ross S.M., King J.R., O'Donovan J.T., Spaner D., 2004a - Intercropping berseem clover with barley and oat cultivars for forage. Agronomy Journal, 96:1719-1729.

Ross S.M., King J.R., O'Donovan J.T., Spaner D., 2004b - Forage potential of intercropping berseem clover with barley, oat, or triticale. Agron. J., 96:1013-1020

Ross S.M., King J.R., O'Donovan J.T., Spaner D., 2005a - The productivity of oats and berseem clover intercrops. I. Primary growth characteristics and forage quality at four densities of oats. Grass Forage Sci., 60:74-86.

Ross S.M., King J.R., O'Donovan J.T., Spaner D., 2005b - The productivity of oats and berseem clover intercrops. II. Effects of cutting date and density of oats on annual forage yield. Grass Forage Sci., 60:74-86.

Salama H.S.A., 2015 - Interactive effect of forage mixing rates and organic fertilizers on the yield and nutritive value of berseem clover (*Trifolium alexandrinum* L.) and annual ryegrass (*Lolium multiflorum* Lam.). Agricultural Sciences, 6:415-425.

Schipanski M.E., Drinkwater L.E., 2012 - Nitrogen fixation in annual and perennial legume-grass mixtures across a fertility gradient. Plant Soil, 357:147-159.

Shoaib M., Ayub M, Zamir M.S.I., Akhtar M.J., 2013 - Dry matter yield of oat-Egyptian clover mixture under varying proportions and different growth stages of oat. Int. J. Agric. Biol., 15: 673-679.

Simmons S.R., Sheaffer C.C., Rasmussen D.C., Stuthman D.D., Nickel D.E., 1995 - Alfalfa establishment with barley and oat companion crops differing in stature. Agron. J., 87:268-272.

Sleugh B., Moore K.J., George J.R., Brummer E.C., 2000 - Binary legumegrass mixtures improve forage yield, quality, and seasonal distribution. Agron. J., 92:24-29.

Tauqir N.A., Khan M.A., Sarwar M., Mahr-un-Nisa, Ali C.S., Lee W.S, Lee H.J., Kim H.S., 2007 - Feeding value of Jambo grass silage and Mott grass silage for lactating Nili Ravi buffaloes. Asian-Aust. J. Anim. Sci., 20(4):523-528.

Thomas R.J., 1992 - The role of legumes in the nitrogen cycle of productive and sustainable pastures. Grass Forage Sci., 47:133-142

Thompson D.J., Stout D.G, Moore T., Mir Z., 1992 - Yield and quality of forage from intercrops of barley and annual ryegrass. Can. J. Plant Sci., 72:163-172.

Vandermeer J.H., 1989 - The ecology of intercropping. Cambridge University Press, Cambridge, UK

Vasilakoglou I., Dhima K., 2008 - Forage yield and competition indices of berseem clover intercropped with barley. Agron. J., 100: 1749-1756

Vinther F.P., 2006 - Effects of cutting frequency on plant production, N-uptake and N2 fixation in above- and below-ground plant biomass of perennial ryegrass-white clover swards. Grass Forage Sci., 61:154-163.

Vranić M., Knežević M., Perčulija G., Bošnjak K., Leto J., 2009 - Intake, digestibility, *in vivo*, N utilization and *in sacco* dry matter degradability of grass silage harvested at three stages of maturity. Asian-Aust. J. Anim. Sci., 22: 225-231.

Wickham S.L., Revell C., Lui A., 2007 - Developing sustainable fodder crop systems with new annual pasture legumes. RIRDC Publication No 07/182, p. 93. Department of Agriculture and Food, Western Australia.

Willey R.W., 1979 - Intercropping-its importance and research needs. Part 2: Agronomy and research approaches. Field Crop Abstracts, 32:73-85.

Witter E., Johansson G., 2001 - Potassium uptake from the subsoil by green manure crops. Biol. Agric. Hortic.: An International Journal for Sustainable Production System, 19(2):127-141.

Zerner M.C., Gill G.S., Vandeleur R.K., 2008 - Effect of height on the competitive ability of wheat with oats. Agron. J., 100:1729-1734.

Zhang F., Li L., 2003 - Using competitive and facilitative interactions in intercropping systems enhances crop productivity and nutrient-use efficiency. Plant Soil, 248:305-312.

Zhang F., Shen J., Li L., Liu X., 2004 - An overview of rhizosphere processes related with plant nutrition in major cropping systems in China. Plant Soil, 260:89-99.