LEGUMES IN CROPPING SYSTEMS: APPROACHES IN MIDWEST UNITED STATES AND SOUTHERN AUSTRALIA

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ABSTRACT

We reviewed two approaches to using legumes in cropping systems in two diverse environments. Alfalfa (*Medicago sativa* L.) and annual medics (*Medicago* sp.) supply forage for livestock and fixed N for subsequent crops in crop rotations. In the midwestern USA, alfalfa is managed as a perennial for hay and silage production in rotations with corn (*Zea mays* L.). In contrast, in southern Australia, medics are grazed as winter annuals in ley rotations with wheat (*Triticum aestivum* L. amend. Thell.). Establishment of productive stands is critical for both legumes; however, for profitable alfalfa production, management to promote persistence of plants is critical. In contrast, for successful use of annual medics in the ley farming system, establishment of adequate seed banks for regeneration of new medic stands each fall is critical. Continued development of new adapted pest resistant cultivars is important for profitable production of each legume. Because of positive effects on the environment, efforts should be made to maintain or increase the use of these legumes by finding new uses for alfalfa or subsidizing use of both legumes.

KEYWORDS

rotations, ley farming, annual and perennial *Medicago*, establishment, persistence.

INTRODUCTION

The virtues of inclusion of legumes in crop rotations have been recognized for over 2000 years. Legumes are noted for their contributions of N, organic matter, and high quality forage. In the Mediterranean climate of southern Australia where annual rainfall is between 20 to 40 cm and occurs mostly during the mild winters, annual legumes such as medics (*Medicago* sp.) and subterranean clover (*Trifolium subterraneum* L.) are grown as winter annuals in rotation with annual cereals (Webber, 1988). In contrast, in the north central United States where rainfall typically ranges from 40 to 60 cm with 65% occurring during the summer growing season, perennial legumes such as alfalfa (*Medicago sativa* L.) and red clover (*Trifolium repens* L.) are grown in rotation with annual crops such as corn (*Zea mays* L.) (Sharp et al., 1995) Our discussion will focus on use of medics and alfalfa in cropping systems.

Alfalfa-corn rotation. In the North Central USA, legumes such as red clover, sweet clover (*Melilotus* sp.), and to a lesser extent alfalfa were used extensively in rotations with corn to supply N and forage until the mid 1900's when inexpensive synthetic N fertilizer became available and livestock numbers on farms began to decline. Since the 1960's when disease resistant, winterhardy alfalfas became available (Barnes et al., 1988), alfalfa has become the primary legume used in rotations. In crop rotations, alfalfa and alfalfa-perennial grass mixtures are grown for 2 to 4 years and are most frequently followed by corn. Alfalfa is frequently grown in mixture with perennial grasses such as smooth bromegrass (*Bromus inermis* Leyss.) or orchardgrass (*Dactylis glomerata* L.) to increase hay drying rates, to reduce bloat potential and to decrease broadleaf weed invasion (Barnes and Sheaffer, 1995).

Ley farming. In the "wheat-sheep zone" of southern Australia, ley farming has constituted the principal system of farming over as much as 40 million hectares for over 40 years (Carter et al., 1982). The traditional ley rotation consists of alternating years of cereal crops and legume pasture (with the latter regenerating from seed set in previous ley years), but now there are a plethora of different forms of rotation which incorporate legume pasture ley. In recent years, there has been a decrease in legume pastures with increasing use of continuous cropping with extended cropping of both cereals and grain legumes interspersed with strategically sown legume pasture leys (Reeves and Ewing, 1993). An extreme form of this system is where the sown pasture ley is not grazed but used as a green manure crop, with farmers reporting up to 70% increases in subsequent cereal yields. The use of legume pasture leys expanded very rapidly from the late 1940's through the early 1960's and was a major factor behind substantial increases in wheat (*Triticum aestivum* L. emend. Thell.) and wool output of the region. Before this, most wheat crops in Australia were grown after a long fallow. Wheat was sown in late autumn after the season break and harvested in early summer. The paddock was then bare-fallowed by tillage for up to 15 months before being resown to the next crop; a practice which led to severe soil structural degradation and nutrient loss (Cornish and Pratley, 1991).

The annual medics most widely grown in Australia are *M. littoralis* Rohde ex Lois., *M. polymorpha* L., *M. rugosa* Desr., *M. scutellata* (L.) Mill., *M. tornata* (L.) Mill., and *M. truncatula* Gaertn. (Crawford et al., 1989). Medic cultivars of these species have been developed with pest resistance and with adaption to specific soil and climatic conditions.

LEGUME ESTABLISHMENT

Because of small seed size and relatively low seedling vigor of alfalfa and annual medics compared to most cereals, management to achieve good stands by using optimum seeding rates, seeding depths, and soil-seed contact for specific soils and by reducing competition with weeds and companion crops is essential. Details of these management guidelines for alfalfa and annual medics are provided by Donald, 1982; Tesar and Marble, 1988; Sheaffer, 1989a, 1989b; Carter et al., 1992).

Some critical soil fertility issues require attention for optimum alfalfa and medic growth. In the north central USA, soil pH, P, and K levels frequently need enhancement by application of lime and fertilizer. In contrast, medics are grown in southern Australia where soils are usually neutral to alkaline but deficiencies of soil P and N are very widespread. Potassium levels in most Australian soils are adequate to maintain legumes. In the USA, S and B may be required for lighter soils; while deficiencies of S and a number of trace elements (Zn, Cu, Mo, Co) are relatively common on the geologically older Australian soils (Stern, 1984).

Alfalfa. Most alfalfa is established using a spring oat small grain companion crop (Simmons et al., 1992). However, spring barley has been shown to be a superior small grain for establishment because of its higher forage quality and nutrient yields (Sheaffer et al., 1994). Companion crops reduce erosion, reduce weed invasion, and provide some assurance of financial return in the seeding year. Small grain companion crops also can compete with alfalfa seedlings for light, water, and nutrients; therefore, companion crops are planted at reduced rates and often harvested for forage before maturity (Sheaffer, 1989a). An alternative approach is the oat-mulch system in which the oat companion crop is killed with a post-emergent grass herbicide at a height of about 15 cm (Curran et al., 1993). This practice can control erosion while producing forage yields and quality similar to solo-seeding with herbicides. About 20% of the alfalfa is solo-seeded without companion crops and using pre- and post-emergent herbicides for weed control (Simmons et al., 1992). With spring seeding and good moisture and fertility, Sheaffer (1983) in Minnesota reported seeding year yields of 2.2 to 5.0 Mg/ha with three cuttings of solo-seeded alfalfa.

Annual Medics. The initial establishment of annual medics in the legume ley occurs in the fall of the ley year with between 2 and up to 20 kg/ha of seed being sown into a prepared seedbed to a depth of about 1 cm. Higher seeding rates are recommended where greater weed populations or more difficult conditions for establishment are expected. Seeding as undersowing in a cereal or other annual crop, while quite cheap is not generally recommended and is less frequently practiced because of greater risks of legume stand failure due to competition for moisture. Regeneration in subsequent years of medics from hard seed occurs each fall.

Seed production for regeneration is crucial to the success of the ley cropping system (Carter et al., 1982). Under Southern Australian growing conditions, annual medics produce seed which is covered with a waxy, water impermeable coat; this being termed “hard seed”. This waxy layer breaks down over one or more seasons to allow water penetration and germination and hence ensures persistence of the sown legume for a number of years from a single year’s seed set (Crawford and Nankivell, 1984). Nevertheless, recent declines in the quality (ie % legume content) of many ley pastures traces in most cases to a lack of legume seed reserve in the soil “bank” (Carter, 1987).

Grazing management of medics is a critical factor. Grazing management can be challenging in some circumstances because grazing pressure must be adequate to remove invading weeds and grasses which compete with medics but not so severe that medic production itself suffers (Carter and Lake, 1985). Ideally, for maximum production, medics should be grazed lightly or grazing deferred during emergence, but medics can be continuously grazed at moderate stocking rates through the rest of the growing season, including through flowering and seed set when growth rates are at their peak. However, excessive grazing and pod consumption will greatly reduce legume regeneration (Carter, 1981), but the time when medics are most at risk in this regard is over the summer/autumn drought period after the pasture has matured (Carter et al., 1992), particularly if pods are left on the soil surface.

Tillage practices have a significant effect on medic establishment. Being small seeded, medics establish best with shallow sowing in a fine seed bed. In some instances, the unavailability of shallow tillage equipment has been a significant factor in the failure of the medic ley system such as occurred when attempts were made to introduce the system into some regions of West Asia and the Mediterranean basin (Riveros et al., 1993). Further, it is important to practice shallow tillage during the cereal phase of the rotation, so as to minimize the amount of pod and hence seed which is buried too deeply in the soil to enable good emergence (Carter and Challis, 1987).

BENEFITS TO THE ROTATION

Forage yield and quality. Ultimately, forage yield and quality of alfalfa and annual medics is closely related to the morphological development of the crop. Forage quality is greatest when legumes are immature and vegetative (Sheaffer et al., 1993; Zhu et al., 1996). Nutrient concentration declines with increasing maturity. This change is associated with increases of fibrous constituents of the stem and a decrease in leaf proportion. Forage yield increases until full flowering stages, but often leaf losses from lower portions of the stem reduce the rate of yield increase after first flower. Seasonal alfalfa yields in the midwest typically range from 4 to 10 Mg/ha (Barnes and Sheaffer, 1995).

Alfalfa is primarily used for production of high quality hay and silage and to a lesser extent for grazing. Yield and quality are greatly influenced by several management factors including soil fertility, insect pest and weed management, and harvest management (Undersander et al., 1994). Assuming good levels of soils fertility and pest management {potato leafhopper [*Empoasca fabae* Harris] and alfalfa weevil [*Hypera punctata* (Gyllenhal)]}, harvest scheduling has the greatest impact on forage yield and quality. Seasonal scheduling of alfalfa harvests is most frequently based on a combination of calendar date, time intervals, and maturity (Sheaffer et al., 1988). For example, Undersander et al. (1994) recommended that for Minnesota and Wisconsin, a first cutting occur at bud stage or between May 15 and 25, a second cutting about 30 days later or at midbud, and subsequent cuttings at 10 to 25% flowering.

In contrast to alfalfa, annual medics are used primarily for grazing. They are generally continuously grazed throughout the growing season, with excess production at flowering and post-flowering stages (the “spring flush”). Medic yields of more than 10 Mg/ha have been measured in plots (Mathison 1973; Lake unpublished data), but good average stocking rates of around 5 sheep/ha indicate that typical pastures are only achieving about half that amount. The amount of excess forage in the spring is dependent on the growing season rainfall (Puckridge and French, 1983), as well as pest numbers and combinations (Allen, 1987). Excess paddock forage harvested as hay can be the major source of animal sustenance until after the season break in the following autumn. In good years, conservation of this excess forage as hay does occur, but this is usually stored for strategic purposes (for example to be used by breeding stock around parturition).

The lack of summer rain means that the quality of ungrazed paddock dry feed does not decline markedly until the autumn season break. However, grazing of dry residues is a selective process, and medic pod and seed can be a significant source of energy and protein for sheep, thereby threatening medic regeneration (Carter, 1981; Carter and Lake, 1985), and leading to general declines in the quality of remnant feed and animal weights (Puckridge and French, 1983).

Rotation effects. Including legumes in rotations has a positive effect on yields of subsequent crops (Voss and Shrader, 1984). These rotation effects have been associated with the addition of N, disease and insect control, improvement of soil physical properties, and improvement of crop root distribution due to reduction in autotoxins (Hesterman, 1988). The cause of many of the non-N rotation effects is unknown, but Crookston (1996) postulated that autotoxins from decomposing roots of corn were a potential cause of yield depression during continuous cropping of corn monocultures.

Most attention has focused on the N rotation effect by legumes. Estimates of the added N provided by alfalfa to corn range from 22 to 155 kg/ha/yr (Hesterman, 1988), and by medics to wheat the range is from 40 to 160 kg/ha/yr (Ladd and Russell, 1983). Nitrogen contribution is influenced by stand density, herbage removal and incorporation, stand age, and tillage. For example, in Minnesota, the first year N credit for corn following alfalfa is 133, 90, and 36 kg/ha for alfalfa stand densities of 136, 18, and less than 9 plants/m^2, respectively (Rehm et al., 1994). Although legumes can fix considerable quantities of N, only part is typically returned because of herbage removal. Nitrogen contribution for subsequent crops is enhanced when alfalfa herbage is incorporated in either fall or late summer. Effective *Rhizobium* sp. have been developed for nodulation of both alfalfa and annual medics. However, because of the diversity of species, the task of developing effective *Rhizobium* for annual medics has been more challenging (Stern, 1984). *Rhizobium* are currently delivered to alfalfa and medics using seed coatings and peat-based systems.

CHALLENGES FOR LEGUMES

Alfalfa. Stand persistence remains a major challenge in profitable alfalfa production. For a crown-forming, perennial plant like alfalfa, cumulative stress has a great effect on persistence (Beuselinck et al. 1994). Consequently, stand densities are usually greatest in the year following seeding and decline thereafter. In the seeding year an adequate stand of alfalfa is about 300 plants/m^2 but stands usually decline to 50 plants/m^2 by the third year. Although stem numbers per plant increase as plant density decreases yields typically decline significantly by the third year after seeding.

There is a complex interaction of uncontrolled environmental and management factors affecting alfalfa persistence (McKenzie et al., 1988). For example, low or fluctuating winter temperatures in the absence of snowcover are major causes of alfalfa winterinjury and stand loss. Likewise, high levels of soil moisture may reduce persistence by reducing winter hardiness or promoting heaving of the tap-rooted alfalfa. Environmental effects may be reduced by planting disease, insect, and nematode resistant cultivars with appropriate winterhardiness for the region, by maintaining high levels of soil fertility especially K, and by avoiding stressful cutting management (Sheaffer et al., 1988).

Defoliation is especially critical for alfalfa persistence because removal of herbage promotes diversion of energy and metabolic resources into regrowth at the expense of plant and root maintenance (Sheaffer et al., 1988). Consequently, it is recognized that frequent cutting of most alfalfa cultivars at vegetative to bud stages of maturity often reduces persistence due to depletion of energy and organic N reserves.

Untimely fall cutting which stimulates alfalfa regrowth before freezing enhances the risk of alfalfa winter injury and reduction of stand persistence (Sheaffer et al., 1988). Consequently in regions with high winter injury potential, it is not recommended to harvest alfalfa from 4 to 6 weeks before the first killing frost. Cutting after the first killing frost usually will not stimulate regrowth, but removal of stubble makes stands more susceptible to frost heaving. Although fall harvesting increases the risk of stand loss, the risk may be justified if forage supplies are short. Therefore, Sheaffer (1989b) proposed a risk assessment approach to making fall cutting decisions with factors such as stand age, cultivar trait, soil fertility, soil drainage, and seasonal harvest frequency considered.

Continued development of alfalfa cultivars with increased disease and insect resistance and enhanced winterhardiness appears critical for increasing persistence. Recent notable developments in this area include germplasm with resistance to the root lesion nematode [*Paratylenchus penetrans* (Cobb) Filipjev & Schu. Stek.], aphanomyces [*Aphanomyces euteiches* Drechs.] and potato leafhopper [*Empoasca fabae* (Harris)] (Barnes et al., 1988). Also, development of winter hardy, grazing tolerant alfalfas (Brummer and Bouton, 1992) will enhance alfalfa persistence as pasture components of rotations.

Perhaps the biggest challenge to the use of alfalfa in rotation is to provide an economically viable use for alfalfa as the number of acres devoted to livestock feeding decreases. Many producers have shifted to all grain rotations (corn-soybean (*Glycine max* (L.) Merr.). In southwest Minnesota, where corn and soybeans are the primary crops, a model biofuel system is being tested to evaluate use of alfalfa for electrical production (Jung et al., 1994). In this system, alfalfa leaves and stems are separated, the stems are gasified, and the leaves are used for livestock feed. Gasification of the biomass produces a low BTU gas which can then be ignited in a combustion turbine for production of electricity. In addition to generation of the leaf meal as a value-added product, removal of leaves reduces the protein content of the gasification fuel thus reducing the NOx pollutant level.

Annual Medics. The initial success of ley farming using medics was promoted by the following: low levels of input required to achieve high quality legume pastures (Donald, 1982), the availability of well adapted ecotypes of pasture legumes which produced hard seed (Crawford et al., 1989); and high wool prices which promoted pasture improvement (Puckridge and French, 1983). However, problems have developed for the ley farming system which threaten its long-term viability. Carter et al. (1982) identified ten major factors which caused a decline in medic stands. These can be grouped into four categories.

The first category relates to infestation particularly with pests and to a lesser extent diseases. Cocks et al. (1980) noted six major pests of annual medic in Australia. The pathogen/pest problem can be overcome by chemical means (e.g., spraying for red-legged earth mite or aphids) or by breeding and selecting resistant cultivars (e.g., Lake 1993a, 1993b). It is likely that continued cultivar development will be necessary for practical, cost effective pest control in these ley systems (Crawford et al., 1989).

A second category which has had a negative impact on ley pastures is the changing edaphic environment. At the start of the ley system, most soils were very deficient in N and also fairly free of weeds, However, once soil N levels increased as a result of legume dinitrogen fixation, the competitive advantage enjoyed by legumes declined and other species particularly grassy weeds, have invaded pastures. Unfortunately, increased use of herbicides to control weeds in the cereal has sometimes caused severe damage to regenerating pasture legumes (Evans et al., 1993). In addition, there has been a serious decline in P application to pasture resulting in less than optimum soil levels for medic growth (Gramshaw et al., 1989). Increased levels of soil acidity associated with annual pasture legume use have been observed, particularly where soils have low buffering capacity or were initially acidic, and this can negatively affect persistence of both the medic and its symbiont *Rhizobium* sp (Howieson and Ewing, 1986).

The third group of factors relate to inadequate or inappropriate management of the changing ley pasture system. Carter et al. (1992) list the five most common reasons for medic stand failure, and all can be rectified by modifying or increasing management inputs. For example, many farmers have increased cropping frequency and hence reduced the total area of pasture ley without commensurate reductions in stock numbers, so that overgrazing now occurs in most seasons.

The fourth and probably most significant factor in the decline of many medic pastures is economics and at least the perceived profitability of pasture improvement against a background of long term decline in terms of trade (Gruen, 1990). A decrease in profitability of sheep and wheat enterprises has resulted in significant reductions in pasture development and hence pastures have been allowed to run down (Vere and Muir, 1986). This is in part due to the fact that much of the profitability associated with growing of an improved legume pasture in a ley farming system is hidden, that is, it is only indirectly realized through the increased yield and quality of the cereal crop, and yet this is now the major source of increased returns afforded by a good medic ley (Krause, 1995). The sensitivity of the farm sector to economic pressures is also illustrated by the decline in P applications to pastures. The price of super-phosphate rose from $18/tonne in 1970 to $130/tonne in the mid 1980's (French, 1987). This was partly but not entirely due to the removal of government subsidies. As a consequence many ley pasture soils are well below optimum P levels for legume growth and legumes are less effective in competing with weeds. The future for ley farming and its prospects for restoration to high levels of successful use appear to lie not in the emphasis on what needs to be done to improve the pasture phase of the rotation, but on creating economic incentives for use of legumes in pastures.

Annual Medics and Alfalfa in the Midwest. Because growth of perennial legumes in rotation may be impractical for grain producers who do not routinely use legumes for livestock feed, we have explored the use of annual alternatives using *Medicago* sp. to produce N, forage, or green manure. We developed an annual alfalfa system for the northern USA which featured use of nondormant cultivars (Sheaffer et al., 1989). The nondormant alfalfa cultivar, Nitro, has greater fall herbage production and seasonal N production than traditionally grown dormant cultivars. Nitro produced 12 and 67% more biologically fixed N for incorporation than nonselected nondormant and dormant cultivars, respectively.

We have also evaluated Australian annual medics as alternative legumes in cropping systems. Zhu et al. (1996a) reported that medics could produce up to 5.5 Mg/ha of forage when used as short-season annual crops for harvest in fall and summer when traditional forage supplies are often inadequate. Spring planted *M. polymorpha* also fixed from 100 to 200 kg/ha of N by early August (Zhu et al., 1996b). Moynihan et al. (1996) evaluated annual medics as intercrops with spring barley (*Hordeum vulgare* L.) to provide ground cover and N for use by subsequent crops. Medics reduced fall weed biomass by 65% and contributed from 66 to 140 kg/ha of total N for incorporation but also sometimes reduced barley yields.

Annual medics have also been no-tilled into wheat stubble following harvest to provide winter soil cover and N (Fisk et al. 1996). Annual medics have also been used as spring seeded green manure crops for winter canola (*Brassica napus* L.) (Shrestha et al., 1996). Despite the great potential for reducing fertilizer N inputs in rotations and increased economic return by using annual legumes, the practice has not been widespread possibly because of concerns about seed costs versus economic returns and unfamiliarity of legume establishment procedures by grain farms.

De Haan et al. (1997) experimented with the use of intercropped annual medics as smother crops in corn. Smother crops are specialized cover species which suppress weeds and eliminate the need for herbicides without reducing crop yields. Medics were seeded concurrently with corn and were effective at suppressing weeds; however, medics also reduced corn yields by about 18%. Additional work by Jeranyama et al. (1995) in Michigan showed that the effectiveness of annual medics as intercrops was increased when medics were seeded 28 days after corn planting at the time of the last cultivation. They found that medics reduced fertilizer needs of a subsequent corn crop by 40%. Despite the benefits, use of annual medics as intercrops with corn is limited by the unpredictable competition between species and inconsistency in favorable conditions for medic establishment.

SUMMARY

We compared two legume based cropping systems which offered some contrasts and similarities. Both legumes have the potential to contribute a high quality forage for livestock consumption; however, medics are most often used by grazing whereas alfalfa is most often harvested and stored as hay and silage. Both alfalfa and annual medics can contribute significant amounts of biologically derived N to subsequent crops in rotations. In addition, growth of both species results in greater soil stability and tilth compared to alternative non-legume based systems. Consequently, at least in an environmental context, they appear to be very sustainable.

A major difference in the two systems lies in the contrast between the perennial nature of alfalfa and the annual medics. Establishment of productive stands is critical for both legumes; however, a key component of successful use of annual medics in the ley farming system is establishment of adequate seed banks for regeneration of new medic stands. In contrast, in midwestern alfalfa production, persistence of established plants is a critical element. In both systems, cultivar development and management have been successful in increasing the efficiency of production.

Both systems face economic challenges. While use of alfalfa or medics may not always be the most profitable enterprise for many farmers, their positive effects on the environment mean that it may be in the best long-term interest of the public to encourage alfalfa production in midwestern USA rotations and in southern Australian ley systems. It is therefore conceivable that public support in the form of government subsidies would be appropriate in some political environments.

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