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Harvest management and cultivar effects on dinitrogen fixation and nitrogen transfer in forage legume:grass mixtures

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Harvest management and cultivar effects on dinitrogen fixation and nitrogen transfer in forage legume:grass mixtures

by

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INTRODUCTION

The capability to fix atmospheric dinitrogen (N₂), and thereby reduce the inherent energy cost of using nitrogenous fertilizers, is one of the main advantages of using perennial forage legumes as components of swards for forage production. Birdsfoot trefoil (Lotus corniculatus L.) (BT) and red clover (Trifolium pratense L.) (RC) are important perennial forage legumes for use as hay or pasture in crop rotations. Despite their traditional usage as a source of nitrogen (N) for cropping systems, little information is available on the amounts of N₂ that BT and RC fix during long-term stands.

The choice of legume for use as a hay or pasture crop is often governed by the costs of establishment and the anticipated longevity of the stand. Rate of N₂ fixation has seldom been a factor in choice of legume species for use in rotations or on set-aside cropland, although N₂ fixation capability is important in estimating the replacement of fertilizer N by legume N (Baldock et al., 1981; Heichel and Barnes, 1984). Alfalfa (Medicago sativa L.) (AL) is a highly productive legume capable of fixing about 170 kg N ha⁻¹ in the establishment year and even more in succeeding years (Heichel et al., 1985). The comparatively high seed costs for AL, however, often mitigate against its use in short-term stands where persistence is unimportant. Red clover or BT are
alternatives to AL. Little information on the N$_2$ fixation capacity of these species in the establishment year and in succeeding years of the stand has been documented, however. Isotope-based studies on N$_2$ fixation by RC and BT are scarce, and the reported amounts of fixed-N range from 60 to 225 kg ha$^{-1}$ yr$^{-1}$ for RC (Boller and Nösberger, 1987; Heichel et al., 1985) and 60 to 120 kg ha$^{-1}$ yr$^{-1}$ for BT (Heichel et al., 1985).

Recent attention has focused on improving forage legume production and their potential contribution to soil fertility through selection of plant genotypes which are especially efficient in N$_2$ fixation. Nitrogen input by N$_2$ fixation and N transfer differ with soil type, altitude, from year to year, and probably with increasing age of the stand (Goodman and Collison, 1984; 1986). It is not fully understood how fixed-N passes from perennial legumes into other parts of the grazing ecosystem, especially under cutting management. It seems very doubtful that the pathway linking the species is as simple as the 'excretion' suggested by Walker et al. (1954). This suggests that transfer of N from clover to grass probably involves decomposition and cycling of complex organic material rather than simple inorganic transfer.

The objectives of this study were two-fold. First, to compare cultivars of BT and RC in terms of N$_2$ fixation and N transfer potentials and, secondly, to examine how harvest
management affected amounts of $N_2$ fixation and N transfer by the same cultivars of BT and RC.
Dinitrogen Fixation By Forage Legumes

Crop production in the central Corn Belt depends almost totally on manufactured fertilizer for adequate N. Commercial fertilizer production is highly dependent on fossil fuel energy. High demands for fossil fuels used in commercial fertilizer production coupled with environmental concerns have generated interest in the need for alternative methods to improve the N nutrition of crops. In comparison, the Rhizobium bacteria that live symbiotically with legumes are capable of converting atmospheric $N_2$ into forms useful for plant growth, thus alleviating the need for fertilizer N.

The soil-building benefits of leguminous crops have been known for centuries. Forage legumes such as AL, BT, and RC, when grown in crop rotations, can provide an alternative source of N to succeeding nonleguminous crops. Reports indicate that fully 80% of AL’s N needs are provided by $N_2$ fixation rather than fertilizer application (Heichel, 1978). Not only are leguminous forages nearly self-sufficient for N needs, but incorporation of plant residues after final harvest leaves appreciable quantities of N in the soil that can become available to the succeeding crop. The protein in the roots and unharvested regrowth of a two- or three-year-old AL stand
is equivalent to 210 kg N ha\(^{-1}\) (Heichel, 1978). About 80% of that total, 170 kg ha\(^{-1}\), is N fixed by symbiosis at no expense to fossil energy resources. The remaining 40 kg ha\(^{-1}\) is derived from soil organic matter. Current research is focusing on whether N\(_2\) fixation can be improved in forage legumes by developing new cultivars. Prior results show promise for identifying particular genotypes with superior N\(_2\) fixation capacity (Nutman et al., 1971; Heichel, 1978; Hardarson and Jones, 1979; Faris, 1983; Barnes et al., 1984).

Recent work in plant physiology indicates that N\(_2\) fixation is not "free fertilizer"; the plant must provide energy in the form of photosynthate. Whether a legume crop "pays" for fixation with decreased yield has been suspected but not determined. Nitrogenase requires energy, in the form of ATP and electrons, to reduce atmospheric N\(_2\) to forms utilizable by the plant. In addition, there are energy costs associated with nodule formation and maintenance, hydrogen loss, and incorporation and transport of newly fixed-N. Silsbury (1977, 1979) estimated the respiratory burden of subterranean clover (Trifolium subterraneum L.) (SC) grown under artificial light with nitrate (NO\(_3^-\)) or N\(_2\). Nodulated plants used 810 mg CO\(_2\) for the synthesis of 1 g dry weight, while nonnodulated plants used only 510 mg CO\(_2\). The carbon cost of 6.5 g C g\(^{-1}\) N estimated by Ryle et al. (1979a, b) and Mahon (1977, 1979) suggests that fixation of 1 kg NH\(_3\) would
cost 15-20 kg dry weight. Therefore, the removal of photosynthetic tissue from forage legumes as a result of clipping or grazing and the competition between vegetative regrowth and nodules for reserve carbohydrates and current photosynthate may adversely affect the capacity of nodules to sustain N\textsubscript{2} fixation. Previous studies have provided good evidence that photosynthate supply to nodules is a major limitation to N\textsubscript{2} fixation (Hardy and Havelka, 1975).

In general, those factors that enhance photosynthesis (e.g., adequate moisture, warm temperatures, bright sunlight, and high CO\textsubscript{2} levels) stimulate N\textsubscript{2} fixation, also. Thus in grass-legume mixtures, shading effects, moisture stress, and decreases in available soil nutrients may reduce photosynthesis by legumes and hence slow nodulation and N\textsubscript{2} fixation rates, both of which depend on an adequate supply of carbohydrates (Prichett and Nelson, 1951; McKee, 1962; Sprent, 1973; Chu and Robertson, 1974; Ruegg and Alston, 1978). Allos and Bartholomew (1959) stated that "the greater the total plant growth and attendant immobilization of N, the larger the fixation." Based on their data, this would suggest that the capacity to fix N\textsubscript{2} from the atmosphere is closely correlated with the size and gross weight of the plant. Contrary to these statements, Hoglund et al. (1979) observed that in grazed pastures, increased clover yield does not necessarily mean a proportional increase in N\textsubscript{2} fixation. This conclusion
was supported by significant positive correlations between soil C:N ratio and clover $N_2$ fixation efficiency. They stated that fixation efficiency was loosely related to soil mineral N availability. Seasonal patterns of fixation efficiency appeared to reflect an interaction of clover growth rate and availability of soil N. High levels of soil mineral N were associated with low levels of $N_2$ fixation and reduced fixation efficiency.

Biologically fixed $N_2$ can contribute significantly to the N nutrition of both legumes and nonlegumes cropped together (West and Wedin, 1985) and is, therefore, important for increased pasture production. The rate of $N_2$ fixation in pastures will depend on the inherent effectiveness of the legume-Rhizobium symbiosis and on environmental conditions (Nutman, 1965; Vincent, 1965). Environmental factors can influence $N_2$ fixation, both through their direct effects on the establishment and functioning of the symbiosis and indirectly through their effects on growth of the plant (Vincent, 1965).

Little quantitative information is available on the seasonal $N_2$ fixation capabilities of certain perennial forage legumes in managed communities. There is also little knowledge of how crop development, crop yielding ability, and climatic conditions affect $N_2$ fixation capacity of these forage legumes. Dinitrogen fixation of a perennial legume
crop varies also with the concentration of total N in above- and below-ground phytomass and the proportion of N in the crop derived from symbiotic N\textsubscript{2} fixation. On grossly N-deficient soils, legumes dominate the sward once deficiencies of other nutrients are corrected, and then N\textsubscript{2} fixation can exceed 500 kg N ha\textsuperscript{-1} yr\textsuperscript{-1} (Sears et al., 1965).

Dinitrogen fixation seems to be more susceptible to environmental stresses, especially low temperatures and moisture deficits, than is growth of the host legume. Legumes tend to flourish under conditions of N deficiency that otherwise would limit growth of companion grasses. Dinitrogen fixation can be enhanced, in the short term, through optimization of management conditions. Examples include the judicious use of N fertilizer forms on the legume swards (Field and Ball, 1978; Murphy et al., 1986) and the proper choice of cultivar and defoliation regime which does least damage to the symbiotic system.

Selection For N\textsubscript{2} Fixation In Forage Legumes

One of the earliest attempts at improving N\textsubscript{2} fixation in legumes made use of \textit{Rhizobium} inoculants. Murphy and Sherwood (1989) expressed that enhancement of N\textsubscript{2} fixation through manipulation of the \textit{Rhizobium} and plant components of the symbiosis must be viewed as a long-term objective. Though
many improvements in inoculant technology have been made and some spectacular responses obtained, in general the benefits of this approach to stimulating N₂ fixation have been disappointing (Halliday, 1985). Results to-date, however, suggest that in the short term, enhanced N₂ fixation may best be achieved through manipulation of the host plant rather than the microsymbiont. Most legume systems have high N₂ fixation potentials which are rarely attained in the field. Limitations imposed by low soil temperatures, drought, high soil N, or salinity on N₂ fixation may best be circumvented by developing cultivars that are less sensitive to these forms of stress. Possibilities for increasing N₂ fixation through plant breeding have been described (e.g., Nutman, 1984; Phillips and Teuber, 1985) and the importance of selecting genotypes in which nitrogenase activity is not rate-limited by low product demand has been emphasized (Mytton, 1988).

It is obviously to the advantage of the plant to have as efficient a symbiosis as possible. Hardarson and Jones (1979) contend that the potential of a cultivar, in terms of its N₂ fixing ability, will depend upon the uniformity of nodulation by the most effective strain of Rhizobium. They also state that it might appear unrealistic to attempt to produce a cultivar which is only compatible with one particular Rhizobium strain. If this strain has been properly screened for effectiveness, competitiveness, and saprophytic
competence, however, then logically, in symbiosis with the appropriate host, it should produce the highest possible yields of fixed-N. Their results indicate a possibility for improving the symbiosis by breeding for uniformity of preference. Results from Nutman et al. (1971) also show that breeding for increased N$_2$ fixation is practicable and probably worthwhile where seed inoculation can introduce the appropriate Rhizobium strain into the soil or where selection can be made for a dominant strain of a soil population. But, where a soil already contains a mixed population of strains, the effect of host selection might be small or negligible.

Nitrogen Fertilization Effects On N$_2$ Fixation

Nitrogen fertilizer has been widely used to increase forage production; however, the use of legumes to replace fertilizer N in forage production is becoming more economically attractive as the cost of N fertilizers increases. The presence of legumes in pastures not receiving N fertilizer has been shown to increase the total herbage yield as well as the yield of the grass component (Dubbs, 1971; Hamilton et al., 1969; Whitehead, 1970; Wilman, 1977). Combinations of legumes and grasses have also resulted in increased N and crude protein content of the grasses (Birch

Most plants obtain all their N requirements for growth by absorption of soil mineral N. Leguminous crops obtain N either from the soil or via their symbiotic association with Rhizobium bacteria (N₂ fixation). Dinitrogen fixation is often increased by small doses of N. A positive response is especially likely if added N is available during the time between exhaustion of the seed reserves and the establishment of an effective N₂-fixing system (Wilson, 1940; Pate and Dart, 1961; Diatloff, 1974). Nitrate-N, however, can depress nodule formation in legumes, an action often attributed to the inhibition of root hair infection (Heichel and Vance, 1979).

Legumes generally compete poorly with grasses for light, water, and nutrients (Stern and Donald, 1962a, b) although in the absence of applied fertilizer, grass-legume associations may outyield grass or legume grown alone (Henzell and Vallis, 1977; Haynes, 1980). Grasses usually have more roots, finer roots, and can explore a greater volume of soil than the legumes with which they are typically associated. When soil mineral N levels are low, legumes are able to utilize atmospheric N₂ for growth. The two sources of N are interactive, however. As mineral N availability increases, N₂ fixation normally decreases (Allos and Bartholomew, 1959; Moustafa et al., 1969). Through the use of $^{15}$N-enriched
fertilizers, it has been established that inorganic-N inhibits
N₂ fixation in legumes (e.g., Allos and Bartholomew, 1959;
McAuliffe et al., 1958) and is likely to have a negative
effect on the amount of N₂ fixed by increasing the grass-to-
legume ratio in the mixture. Inclusion of a grass in
mixtures, however, can stimulate N₂ fixation by the legume.
Craig et al. (1981) reported that legumes mixed with grasses
had higher acetylene reduction rates than those in pure stand.
They also suggested that grass may excrete some biologically
active substances that stimulate legume N₂ fixation. A likely
reason for grass stimulation of legume N₂ fixation is
depletion of soil N by the grass. This would reduce nitrate
inhibition of nodulation and nodule function, and increase the
reliance of legumes on N₂ fixation (Brophy et al., 1987). The
severity of this N-inhibition depends on the legume species
(Allos and Bartholomew, 1959), cultivar (Danso et al., 1987;
Hardarson et al., 1984; Rennie et al., 1982), and the cropping
system (Walker et al., 1956). The inhibitory effects of
mineral N on legume nodulation may be moderated by the
Rhizobium strain (Murphy, 1987) and the successful
establishment of elite strains which have high tolerance to
nitrate. This could enhance N₂ fixation activity, even in
fertile soils that contain abundant N. The application of
Rhizobium technology in the field continues to be limited by a
lack of understanding of the basic factors affecting the survival and symbiotic competence of strains in the soil.

Defoliation Effects On N₂ Fixation

Periodic harvesting of shoots of forage legumes removes a primary source of energy for maintaining N₂ fixation (Moustafa et al., 1969), nodule structure and function (Butler et al., 1959; Wilson, 1942), and for the initiation of new nodules. The ability of nodules to remain functional after removal of the vegetative shoots may depend upon a number of factors (e.g., plant species, microsymbiont, nodule morphology, rate of shoot regrowth, nutrient availability, and competition between plant parts for energy). Vance et al. (1979) showed that harvesting (removal of 80% of the aerial portion of the plant) significantly altered N₂(C₂H₂) reduction capacity, nodule enzymology, and nodule development in seedling AL. It has been demonstrated in field and glasshouse studies that when white clover (Trifolium repens L.) (WC) is defoliated, N₂ fixation is depressed (Moustafa et al., 1969; Chu and Robertson, 1974; Halliday and Pate, 1976) and root and nodule breakdown occurs (Butler et al., 1959; Chu and Robertson, 1974), releasing N to the rooting medium. Chu and Robertson (1974) showed that severe defoliation of WC caused degradation of leghemoglobin (coloration change of nodules from pink to
green to brown). Because the presence of leghemoglobin is associated with \( \text{N}_2 \) fixation (Virtanen et al., 1947), such changes in coloration probably signify a loss or a reduction in \( \text{N}_2 \) fixation activity. It led also to a temporary but marked decrease in the \( \text{N}_2 \) fixation capacity of the nodules as measured by the acetylene reduction assay. Recovery of normal activity by the nitrogenase system took about 10 d. Recovery of the pink color occurred progressively from the apex over approximately 12 d. Many nodules did not survive, however.

Gordon et al. (1986) showed that soluble protein, leghemoglobin, and carbohydrate contents of WC nodules declined after defoliation, but increased again to control levels as new leaf tissue appeared. The extent of reduction was dependent on the severity of defoliation. The initial decline in \( \text{N}_2 \) fixation, and the respiration associated with it, appeared not to be related to the instantaneous carbohydrate content of nodules, but rather to the supply of current photosynthate from the shoot. It was found that nodule respiration was reduced by 80-90\% within 2-3 h when photosynthesis was eliminated by defoliation. This suggested that the nodules became starved of carbohydrate.

Numerous reports have indicated that defoliation results in a severe loss of nodules. Dinitrogen fixation in legumes requires a large expenditure of energy from photosynthate for nodule growth and function. The removal of photosynthetic
tissue from forage legumes at harvest, and the competition between vegetative regrowth and nodules for reserve carbohydrates and current photosynthate, may adversely affect the capacity of nodules to sustain N₂ fixation (Cralle and Heichel, 1981). Previous investigators reported a decline in nodule numbers following herbage removal for several forage species (Butler et al., 1959; Whiteman, 1970; Wilson, 1942). Wilson (1942) reported that WC lost about a third of its nodules after harvest. Butler et al. (1959) found that defoliation and shading of RC and BT caused a severe reduction in nodule number, while nodules of WC apparently were not affected. The mechanisms controlling nodule degeneration, nodule loss, and nodule replenishment after harvest are not understood in entirety for any forage legume.

Although nodules reportedly become physically detached from perennial legume roots after harvest (Butler et al., 1959; Gibson, 1975; Gibson, 1977; Whiteman, 1970; Wilson, 1942), there are conflicting results regarding loss of nodule mass after shoot removal. Vance et al. (1979) showed that nodule senescence occurred in AL but that nodules were not shed and their structural deterioration was repaired when new leaf tissue grew. Only when about 80% of the shoot weight was removed was nodule deterioration observed. Nodule deterioration, however, proved to be only temporary. Gordon et al. (1986) found no visible evidence of nodule
deterioration in defoliated WC plants when less than 75% of the shoots were removed. When 80 to 85% of shoots were removed, there was a visible effect on nodule appearance. They changed color from pink to dark green and appeared to be dying. Microscopic examination of nodule sections indicated that only after very severe defoliation (80 to 85% shoot removal) was nodule deterioration evident.

Since factors other than clipping may cause the plant to shed its nodules (e.g., shading, moisture stress, nutrient deficiencies, low temperatures), it is difficult to say how extensively nodule losses occur in pastures where the grasses and perennial legumes are moderately or severely defoliated by grazing. It would seem, however, if such factors as defoliation or soil drying are repeated often or even occasionally throughout the growing season, and a few or many new nodules appear each time, that significant amounts of N may be released from the decomposing nodules and become available to the associated nonlegume (Wilson, 1942). Agronomic studies on the N economy of legume-grass associations have shown that factors which depress the legume component (e.g., severe defoliation and high levels of soil N) also increase the rate at which legume fixed-N is released to the soil and made available for grass growth (Wilman, 1970). The release of N to the soil may inhibit either additional
initiation of legume nodules or the nitrogenase activity of nodules already present (Craig et al., 1981).

Transfer Of Fixed-N To Associated Grass

Interest in using forage legumes in legume-grass associations has been stimulated further when considering the possibility that fixed-N may also become available to companion grasses via N transfer (Haystead and Marriott, 1978). Nitrogen transfer is the movement of N from one plant to another. Nitrogen transfer in mixed swards of forage legumes and grasses has been inferred (Bland, 1967; Cowling and Lockyer, 1967; Johansen and Kerridge, 1979; Simpson, 1976). Benefits of intercropping legumes and nonlegumes seem greatest in low soil N regimes, possibly due to N transfer. The amount of N transferred to the associated nonlegumes will depend on those factors affecting the amount of N\textsubscript{2} fixed and the efficiency of transfer. Thus, species and cultivar of legume, water and nutrient supply, temperature, height and frequency of defoliation and grazing can be involved (Vallis, 1978).

Estimates of transfer range from 26 to 154 kg N ha\textsuperscript{-1}, depending upon species composition of the sward, productivity, and duration of crop growth (Brophy et al., 1987). Baylor (1974) noted that the inclusion of a legume in a grass sward
usually resulted in increased yield, higher quality, and improved seasonal distribution of forage. This benefit is attributed mainly to the transfer of N symbiotically fixed by the legume to the associated grass, either by direct excretion from the legume nodule-root system (Ta et al., 1986) and/or by decomposition of nodule and root debris (Ta and Faris, 1987a, b; Whitney and Kanehiro, 1967).

There are several known mechanisms of N transfer between legume and grass; the relative importance of the different mechanisms will depend on growing conditions, management practices, and the species used. There are "indirect" mechanisms of transfer, notably by animal ingestion of herbage from one area and excretion onto a different area of pasture. In intensively-managed grazing systems, animals consume approximately 80% of the available standing crop (Kemp et al., 1979). Most of the ingested N contained in the grasses and legumes is excreted; the amount retained will vary with the type of livestock. A fattening animal may excrete over 95% of the ingested N, whereas a lactating dairy cow may excrete about 75% (Walker et al., 1954). Plant N derived from N₂ fixation, soil N, or fertilizer sources also may be rapidly recycled by mineralization of plant residues in the soil resulting from grazing or treading by animals. The ammonium- and nitrate-N forms arising from such processes may be utilized by plant roots and soil biota or lost from the system.
e.g., by volatilization or leaching (Murphy and Sherwood, 1989). Recycling of legume N by grazers is an important transfer mechanism (Vallis, 1978), although percentage utilization of the legume forage and potentially large N losses from leaching and weathering (Ball et al., 1979) may limit the efficiency of these pathways.

An alternative, and in some cases more important route, is that of "direct" or "underground" transfer between neighboring plants. This involves the release of legume N either by the excretion of soluble N compounds directly from the root itself or from loss and decomposition of roots and nodules in response to defoliation, shading, and low temperatures (Simpson, 1976; Newbould and Haystead, 1978). "Direct" N transfer is much less dependent on animal behavior. Gaseous and leaching losses are also minimized. Thus, the N status and productivity of the grasses in a leguminous pasture can depend on the capacity and/or the efficiency of the associated legume to transfer N "directly."

Legumes can supply N to associated nonlegumes by excretion of soluble amino acids from living root systems (Virtanen et al., 1937b), but long, cool days with low light intensity are needed for significant transfer (Wyss and Wilson, 1941). Virtanen et al. (1937a) consistently demonstrated the direct excretion of N and consequent increase in N uptake by the nonlegume. The amount of N excreted
sometimes amounted to about half the total \( N_2 \) fixed. Subsequent work by Wilson and Wyss (1937) and Wilson and Burton (1938) confirmed that temperature, shade, and length of day all affected excretion of \( N \). Strong and Trumble (1939) also found that shading may induce \( N \) excretion by legumes.

Cutting of legumes can result in the death of root and nodule tissue with a consequent release of \( N \) to the soil (Whitehead, 1970). This release of \( N \) may inhibit either additional initiation of legume nodules or the nitrogenase activity of nodules already present. Grasses grown in association with legumes may absorb the newly released \( N \) and thus reduce the soil-\( N \) mediated inhibition of legume \( N_2 \) fixation. The inclusion of a legume in a pasture mixture commonly, but not invariably, increases the \( N \) uptake of the nonleguminous component. Competition by the legume for mineral \( N \) may reduce \( N \) transfer to grass in some swards, however (Vallis, 1978).

Previous studies (Brophy et al., 1987; Mallarino et al., 1990) have shown that percentage of grass \( N \) derived from \( N \) transfer tended to increase as the season progressed. Several factors could contribute to this seasonal increase, including increased depletion of available soil \( N \), greater \( N_2 \) fixation capability by the legumes, and greater root intermingling. Some \( N \) may be released in complex forms such as cell debris and root tissue. Such forms of \( N \), or \( N \) released in soluble
and easily available forms rapidly immobilized by soil microflora, may not be available to associated grasses until late in the season, or even until succeeding seasons following turnover of microbial biomass (Haystead and Marriott, 1979). Loss of nodule or root mass to the soil does not necessarily imply that significant N transfer will occur. The N concentration of these tissues may be small because of remobilization of N before shedding (Cralle and Heichel, 1981). Furthermore, legume-derived N may be temporarily tied up as organic N in the soil (Haystead and Marriott, 1979). Part of the N in legume residues and excreta will be immediately available, or quickly become available, for re-uptake. The remainder will be converted to stable organic compounds, which become available to plants only slowly.

Little information is available on the quantities of N that are added to the soil annually by legumes in plant litter within grazed pastures, but considerable proportions of the herbage are obviously involved, depending on grazing efficiency. There is no doubt, then, that legume litter is potentially a major avenue for transfer of N, but its value as a source of N will depend on its chemical composition, particularly its N content (Vallis, 1978). In pastures containing WC, transfer of N from decomposing plant material usually has been attributed mainly to the turnover of ephemeral roots and nodules (Butler and Bathurst, 1956;
Russell, 1961; Whitehead, 1970). If this is so, treatments such as defoliation and shading, which restrict the supply of carbohydrate to the root system and thus cause the death of nodule tissue, might be expected to increase the rate of N transfer (Butler et al., 1959; Whiteman, 1970).

It is now generally agreed that primary N transfer from legumes to the soil is mediated via complex organic matter arising from the decomposition of nodular or root material. A recent report by Ta and Faris (1987), however, lends support to an involvement of rapid transport pathways. It has been shown by using N isotope dilution that, over a production season, grass accumulates a significant amount of N as a result of transfer from the legume component in a mixed sward and stress factors such as shading, defoliation, and low temperature promote this transfer (Haystead and Marriott, 1979). Clearly, transfer of N from the legume is not a predictable process. Factors such as soil temperature, soil pH, and the C:N ratio control the internal N-cycle of the soil and consequently the rate at which organic N is mineralized, immobilized, and transferred to grass species via the soil microbial pool (Murphy and Sherwood, 1989).
MATERIALS AND METHODS

Site Characteristics

This field study consisted of two experiments, both conducted at the Iowa State University Agronomy and Agricultural Engineering Research Center located 13 km west of Ames, Iowa. The two experiments were conducted on separate but similar sites. Soil within the first experimental area (Exp. 1) was a Fine-loamy, mixed, mesic Typic Hapludoll. Soil within the second experimental area (Exp. 2) was a Fine-loamy, mixed, mesic Typic Haplaquoll. Soil pH of the two sites was 6.2 for Exp. 1 and 6.9 for Exp. 2. Nutrient status of the two sites showed available P of 66 and 84 kg ha\(^{-1}\) and exchangeable K of 224 and 230 kg ha\(^{-1}\) for Exp. 1 and Exp. 2, respectively (Iowa State University Soil Testing Laboratory). A N-depletion treatment was applied to each site to reduce the available soil N pools. For Exp. 1, oats (Avena sativa L.) were grown (1987) and all growth removed from the site. For Exp. 2, oats followed by sorghum (Sorghum bicolor (L.) Moench) were grown (1988) and all growth removed from the site. These treatments resulted in inorganic soil N concentrations of 11.16 and 8.98 mg kg\(^{-1}\) at the beginning of Exps. 1 and 2, respectively.
Experiments and Treatments

Experiment One

This experiment was conducted to compare the \( \text{N}_2 \) fixation and \( \text{N} \) transfer potentials of four RC and four BT cultivars. Four cultivars each of RC and BT were seeded in binary mixtures with orchardgrass (*Dactylis glomerata* L.) (OG). Cultivars of BT included in this experiment were APB-8701 (experimental cultivar), Dawn, Fergus, and Norcen. Red clover cultivars included in this experiment were APR-8701 (experimental cultivar), Arlington, Mammoth, and Redland II. The OG cultivar Dawn was used as a nonfixing control (reference crop) and as the grass component of the legume-grass mixtures for the isotope dilution study. This experiment was planted on 7 Apr. 1988 and evaluated for 2 yr (1989 and 1990).

Experiment Two

This experiment was conducted to examine how harvest management affects the \( \text{N}_2 \) fixation and \( \text{N} \) transfer potentials of four RC and four BT cultivars grown in binary mixtures with OG. Red clover, BT, and OG cultivars used in this experiment were the same as described in Exp. 1. Two cutting managements (3- and 6-wk intervals) were imposed on
each of the RC and BT mixtures. This experiment was planted on 18 Apr. 1989 and evaluated for 2 yr (1990 and 1991).

Cultivar Descriptions

The RC cultivar APR-8701 was developed by AgriPro Biosciences, Incorporated (ABI). Desirable characteristics for which it was selected include increased rate of acetylene (C$_2$H$_2$) reduction, larger roots with more branches, increased nodule mass, and improved winter hardiness as compared with more commonly used cultivars. Redland II is a medium red clover released by the North American Plant Breeders (NAPB). It is a persistent cultivar and has resistance to both northern and southern anthracnose and powdery mildew.

Arlington was developed by the USDA and the University of Wisconsin and released in 1973. It is resistant to powdery mildew and northern anthracnose with moderate resistance to bean yellow mosaic virus. Mammoth is considered a "one cut" red clover in production years. It performs well but smooth stems and leaves make it susceptible to the potato leaf hopper (Empoasca fabae Harris). It blooms later and yields less than medium red clovers.

The BT cultivar APB-8701, like APR-8701, was developed by ABI and also was selected for increased rate of C$_2$H$_2$ reduction, larger roots with more branches, increased nodule
mass, and improved winter hardiness as compared with more commonly used BT cultivars. Norcen was developed cooperatively by researchers in several North Central states. It is a high yielding cultivar and also a good seed producer. Fergus was developed by the Kentucky Agricultural Experiment Station. It is a high yielding, semi-erect cultivar. Dawn was developed by the USDA and the Missouri Agricultural Experiment Station. It also shows good persistence and yield capability.

Plant Establishment and Maintenance

Legume seed was inoculated just prior to planting using specific Rhizobium inoculant (Rhizobium trifolii for RC and Rhizobium loti for BT). In both experiments, small plots were seeded with an Almaco® Forage Plot Seeder. Alternating rows of legume and grass were established with row spacings of approximately 8 cm. Forty plots each measuring 3 x 5 m were seeded for Exp. 1 and eighty plots each measuring 1.5 x 5 m were seeded for Exp. 2. The seeding rates for the two experiments are shown in Table 1.
Table 1. Seeding rates for red clover, birdsfoot trefoil, and orchardgrass

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Species^a</th>
<th>Rate (kg ha^-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BT</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>RC</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>OG</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>OG (Ref^b)</td>
<td>18</td>
</tr>
<tr>
<td>2</td>
<td>BT</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>RC</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>OG</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>OG (Ref)</td>
<td>20</td>
</tr>
</tbody>
</table>

^aBT = birdsfoot trefoil; RC = red clover; OG = orchardgrass.

^bRef = pure stand orchardgrass used as reference for isotope dilution study.

Experimental Design

Experiment One

A total of four replications per legume species was seeded in a completely randomized design. Each replication included four legume-grass mixtures (one mixture per legume cultivar) and a pure OG reference plot. A single reference value of $^{15}$N %atom-excess averaged over all reference grass plots was used for $N_2$ fixation and $N$ transfer calculations on each harvest. Data from reference plots were not used in any statistical analyses.
Experiment Two

The factorial combinations of four legume cultivars grown in association with OG subjected to two different harvest managements (3-cut and 6-cut) yielded a total of eight treatments for each legume species. Four replications per legume species were seeded in a split-plot randomized complete block design with cultivars used as whole plots and harvest management used as sub-plots. Each replication included eight legume-grass mixtures (two for each of the four cultivars of each legume species) and two pure OG reference plots. A single reference value of $^{15}$N %atom-excess was averaged for each replication and each harvest management as explained in Exp. 1.

Isotopic Labelling of Plots

Experiment One

An isotope dilution study was conducted to estimate the amounts of N$_2$ fixed and transferred to associated OG (Fried and Middelboe, 1977; Vallis et al., 1967) by the different cultivars. In March, 1989 and again in March, 1990, prior to the appearance of spring growth, a solution of $^{15}$N enriched (99.7%) ammonium sulfate (0.15 g $^{15}$N isotope per plot) was sprinkled onto a 1-m$^2$ microplot (0.5 x 2 m) within each plot and then immediately watered down with approximately 5 L of
water. A single annual application at such a low rate would not likely affect plant growth or N₂ fixation significantly.

**Experiment Two**

Labelling of Exp. 2 was the same as described for Exp. 1. Plots were labelled with ¹⁵N enriched fertilizer (as described for Exp. 1) in March, 1990 and again in March, 1991, prior to the appearance of spring growth.

**Harvest Management**

**Experiment One**

Three harvests were taken in 1989 and again in 1990. Harvest dates were 30 May, 10 July, and 15 Aug. 1989 and 6 June, 18 July, and 28 Aug. 1990. Estimates of DM yield were made by harvesting a 0.8 x 3.5 m swath with a Jari® sickle mower to a 6-cm stubble height. Dry matter samples were dried in a forced-air oven at 60 °C for 48 h.

Plant material to be used for N₂ fixation and N transfer analyses was collected by hand-harvesting a 0.75 m² area from each plot to a 6-cm stubble height. Green material was separated into legume and nonlegume fractions, dried in a forced-air oven at 60 °C for 48 h, and ground to pass a 1-mm screen in a Udy Cyclone® mill.
**Experiment Two**


Plant material to be used for $N_2$ fixation and $N$ transfer analyses was collected in a manner similar to that explained for Exp. 1. Estimates of DM yield for the 6-cut system were made by harvesting a 0.4 x 4.4 m swath with a Snapper® rotary lawnmower to a 6-cm stubble height. Estimates of DM yield for the 3-cut system were made by harvesting a 0.8 x 4.4 m swath with a Jari® sickle mower to a 6-cm stubble height. All DM yield samples were dried in a forced-air oven at 60 °C for 48 h.

**$N_2$ Fixation and $N$ Transfer Analyses**

An isotope dilution study was conducted to estimate $N_2$ fixation and $N$ transfer in both experiments. Total plant $N$ was determined via the "Kjeldahl" method (Bremner, 1965) on all samples. The Kjeldahl distillate was then analyzed by
mass spectrometry (Fiedler and Proksch, 1975) to determine isotopic composition of the grass and legume fractions. A single reference value of \( ^{15}N \) %atom-excess averaged over all reference grass samples was used for \( N_2 \) fixation and \( N \) transfer calculations on each harvest.

The formulas used to perform the various calculations used in this study are:

\[
\%Ndfa = (1 - \frac{\text{atom } ^{15}N \text{ excess in legume}}{\text{atom } ^{15}N \text{ excess in ref. grass}}) \times 100
\]

\[
\%Ngdfa = (1 - \frac{\text{atom } ^{15}N \text{ excess in grass}}{\text{atom } ^{15}N \text{ excess in ref. grass}}) \times 100
\]

\[
FNY = (\text{Legume DM}) \times (\% \text{ total N in legume}) \times (\%Ndfa)
\]

\[
TNY = (\text{OG DM}) \times (\% \text{ total N in OG}) \times (\%Ngdfa)
\]
RESULTS

In this section, the results from two experiments conducted in this study are discussed separately. In Exp. 1, \( N_2 \) fixation and \( N \) transfer potentials of four BT and four RC cultivars are compared, each grown in mixture with OG. Herbage DM yield of each mixture was examined, also. In Exp. 2, the effects of harvest management on DM yield, \( N_2 \) fixation, and \( N \) transfer capabilities are examined. The same four cultivars of BT and RC, each grown in mixture with OG, were used in Exp. 2. In the discussion of both experiments, \( N_2 \) fixation will be expressed either as the proportion of legume \( N \) derived from the atmosphere (\( \%N_{\text{dfa}} \)) or as legume fixed-\( N \) yield (FNY) which is the amount of legume \( N \) derived from the atmosphere expressed on an area basis. Nitrogen transfer from legume to associated grass will be expressed either as proportion of grass \( N \) derived from the atmosphere (\( \%N_{\text{gdfa}} \)) or as grass transferred-\( N \) yield (TNY) which is the amount of grass \( N \) derived from the atmosphere expressed on an area basis.
Experiment One

Birdsfoot trefoil dry matter yield

Total-season DM yields in 1989 ranged from 4.9 to 5.8 Mg ha\(^{-1}\) (Table 2), although differences (P≤0.05) were nonsignificant. Dry matter yields were always greatest in harvest 1 (H1) and decreased over time (Figure 1). Yields in H1 exceeded 2.5 Mg ha\(^{-1}\) while DM yields in harvest 3 (H3) were 0.8 Mg ha\(^{-1}\) or less. In harvest 2 (H2) and H3, the Dawn mixture (DWN-OG) had the greatest DM yields of the four mixtures, although yields did not differ (P≤0.05) among any of the mixtures for any of the three harvests. Likewise, the APB-8701 mixture (APB-OG) had the lowest DM yields in H2 and H3.

Total-season DM yields in 1990 ranged from 8.1 to 9.0 Mg ha\(^{-1}\) (Table 2) with APB-OG having a significantly (P≤0.05) lower total yield of herbage DM than the other mixtures. These yields represent an increase of as much as 84% over 1989. Dry matter yields of 1990 were always greatest in H1 and decreased over time (Table 2 and Figure 2). Yields for H1 ranged from 3.5 to 4.2 Mg ha\(^{-1}\), and were as much as 51% greater than DM yields of H1 in 1989. Total DM yields of H2 were as much as 92% greater than DM yields of H2 in 1989, while H3 of 1990 yielded as much as 242% more DM than H3 of 1989. The Fergus mixture (FER-OG), Norcen mixture (NOR-OG)
Table 2. Herbage dry matter yield of four birdsfoot trefoil/orchardgrass mixtures grown in two different years

<table>
<thead>
<tr>
<th>Year</th>
<th>H&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Cultivar&lt;sup&gt;a&lt;/sup&gt;</th>
<th>APBT</th>
<th>DWN</th>
<th>FER</th>
<th>NOR</th>
<th>AVG&lt;sup&gt;c&lt;/sup&gt;</th>
<th>LSD&lt;sup&gt;d&lt;/sup&gt;</th>
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<td></td>
<td></td>
<td>Mg ha&lt;sup&gt;-1&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>1</td>
<td>2.9</td>
<td>2.7</td>
<td>2.8</td>
<td>3.3</td>
<td>2.9</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.5</td>
<td>2.0</td>
<td>1.7</td>
<td>2.0</td>
<td>1.8</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.5</td>
<td>0.8</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AVG</td>
<td>1.6</td>
<td>1.8</td>
<td>1.7</td>
<td>2.0</td>
<td>1.8</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LSD</td>
<td>0.6</td>
<td>0.4</td>
<td>0.8</td>
<td>1.2</td>
<td>0.4</td>
<td>NS</td>
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<td></td>
<td>TOT&lt;sup&gt;e&lt;/sup&gt;</td>
<td>4.9</td>
<td>5.5</td>
<td>5.1</td>
<td>5.8</td>
<td>5.3</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>1</td>
<td>3.5</td>
<td>4.1</td>
<td>4.1</td>
<td>4.2</td>
<td>4.0</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.9</td>
<td>2.8</td>
<td>2.9</td>
<td>2.7</td>
<td>2.8</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.6</td>
<td>1.8</td>
<td>2.0</td>
<td>1.9</td>
<td>1.8</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AVG</td>
<td>2.7</td>
<td>2.9</td>
<td>3.0</td>
<td>3.0</td>
<td>2.9</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LSD</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.4</td>
<td>0.2</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TOT&lt;sup&gt;e&lt;/sup&gt;</td>
<td>8.1</td>
<td>8.7</td>
<td>9.0</td>
<td>8.9</td>
<td>8.7</td>
<td>0.6</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.

<sup>e</sup>TOT = total-season yield.
Figure 1. Herbage dry matter yields from three harvests of four birdsfoot trefoil/orchardgrass mixtures grown in 1989. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, $P<0.05$ (NS = no significant main effect)
Figure 2. Herbage dry matter yields from three harvests of four birdsfoot trefoil/orchardgrass mixtures grown 1990. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
and DWN-OG were all significantly greater (P≤0.05) than APB-OG in DM yields for H1 of 1990. No differences were shown among mixtures for H2 and H3.

Mean BT DM yields tended to be related negatively to legume proportion (DM basis) in the mixtures for 1989, while relationships were positive for all four mixtures in 1990 (Table 3). Regressions usually were not significant (P<0.05) for either year, however. Legume proportions for 1989 usually were greater than 50% for all cultivars in all harvests and averaged more than 60% for the entire 1989 growing season (mean of all cultivars and all harvests) (Table 4). Legume proportions usually were highest for all cultivars in H2. When averaged over three harvests, Norcen maintained the highest legume proportion in the mixture (65.5%) and Dawn had the lowest (57.1%), although differences were not always significant (P≤0.05). Legume proportions for 1990 were usually less than 50% for all cultivars in all harvests and averaged 41.5% over the entire growing season (Table 4). When averaged over three harvests, Fergus maintained the greatest legume proportion (47.0%) and Dawn had the least (37.1%). Legume proportions were always lower in 1990, however, differences were not always significant (P≤0.05).
Table 3. Regression equations of dry matter yield (DM), N\textsubscript{2} fixation (%Ndfa), fixed-N yield (FNY), N transfer (%Ngdfa), and transferred-N yield (TNY) on percentage legume in four birdsfoot trefoil/orchardgrass mixtures.

<table>
<thead>
<tr>
<th>CV\textsuperscript{a}</th>
<th>VAR\textsuperscript{b}</th>
<th>1989</th>
<th>1990</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Equation</td>
<td>R</td>
<td>SE\textsuperscript{c}</td>
</tr>
<tr>
<td>APBT</td>
<td>DM</td>
<td>2.0 - 0.01X</td>
<td>0.07</td>
</tr>
<tr>
<td>DAWN</td>
<td>DM</td>
<td>0.3 + 0.03X</td>
<td>0.38</td>
</tr>
<tr>
<td>FERGUS</td>
<td>DM</td>
<td>4.3 - 0.04X</td>
<td>0.34</td>
</tr>
<tr>
<td>NORCEN</td>
<td>DM</td>
<td>3.9 - 0.03X</td>
<td>0.27</td>
</tr>
<tr>
<td>APBT</td>
<td>%Ndfa</td>
<td>93.1 + 0.01X</td>
<td>0.01</td>
</tr>
<tr>
<td>DAWN</td>
<td>%Ndfa</td>
<td>88.2 + 0.12X</td>
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</tr>
<tr>
<td>FERGUS</td>
<td>%Ndfa</td>
<td>111.0 - 0.24X</td>
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</tr>
<tr>
<td>NORCEN</td>
<td>%Ndfa</td>
<td>82.4 + 0.17X</td>
<td>0.36</td>
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<tr>
<td>APBT</td>
<td>FNY</td>
<td>7.5 + 0.43X</td>
<td>0.26</td>
</tr>
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<td>DAWN</td>
<td>FNY</td>
<td>-6.7 + 0.73X</td>
<td>0.45</td>
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<td>FNY</td>
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</tr>
<tr>
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<td>%Ngdfa</td>
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</tr>
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<td>FERGUS</td>
<td>%Ngdfa</td>
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<td>NORCEN</td>
<td>%Ngdfa</td>
<td>35.5 - 0.60X</td>
<td>0.39</td>
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<tr>
<td>APBT</td>
<td>TNY</td>
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<td>DAWN</td>
<td>TNY</td>
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<td>FERGUS</td>
<td>TNY</td>
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<tr>
<td>NORCEN</td>
<td>TNY</td>
<td>5.3 - 0.09X</td>
<td>0.35</td>
</tr>
</tbody>
</table>

\textsuperscript{a}CV = cultivar.

\textsuperscript{b}VAR = response variable; DM in Mg ha\textsuperscript{-1}, FNY and TNY in kg ha\textsuperscript{-1}.

\textsuperscript{c}SE = square root of the residual mean square; NS = no significant main effect (P≤0.05).
Table 4. Legume proportion of four birdsfoot trefoil/orchardgrass mixtures grown in two different years

<table>
<thead>
<tr>
<th>Year</th>
<th>H&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Cultivar&lt;sup&gt;a&lt;/sup&gt;</th>
<th>APBT</th>
<th>DWN</th>
<th>FER</th>
<th>NOR</th>
<th>AVG&lt;sup&gt;c&lt;/sup&gt;</th>
<th>LSD&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>1</td>
<td>52.1</td>
<td>60.4</td>
<td>57.0</td>
<td>64.5</td>
<td>58.5</td>
<td>NS</td>
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<td></td>
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<td>67.0</td>
<td>63.3</td>
<td>66.8</td>
<td>71.0</td>
<td>67.0</td>
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<td></td>
<td>3</td>
<td>54.4</td>
<td>47.7</td>
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<td>58.1</td>
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<sup>a</sup>APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.


N$_2$ fixation by birdsfoot trefoil

Values of %Ndfa for the four cultivars ranged from 88.3 to 98.7% over three harvests in 1989 (Table 5). Values of %Ndfa were usually highest in H1 and tended to decrease over time (Figure 3). Lowest values for all cultivars, except APB-8701, were observed in H3. Cultivars did not differ (P≤0.05) in %Ndfa in any harvest. When averaged over the three harvests, Fergus had the greatest %Ndfa (95.3%) and Norcen had the least (93.3%), however, these differences were not significant (P≤0.05). Total-season %Ndfa (average of all cultivars and all harvests) was 94.3%, i.e., in 1989 more than 90% of the N in BT came from fixation.

Values of %Ndfa for the four cultivars in 1990 ranged from 87.9 to 98.6% over three harvests (Table 5). Values of %Ndfa for all cultivars were greatest in H1 and least in H2 (Figure 4). There were no differences (P≤0.05) observed among cultivars in either H1 or H3. In H2, both Norcen and APB-8701 had greater (P≤0.05) %Ndfa than Fergus. When averaged over the three harvests, Norcen and APB-8701 had the greatest %Ndfa (96.6%) and Fergus had the least (94.5%). Total-season %Ndfa was 96.0%, i.e., in 1990 more than 95% of the N in BT came from fixation. Percentage Ndfa tended to be related positively to legume proportion in the BT mixtures for 1989, while %Ndfa tended to be related negatively to legume
Table 5. Percentage nitrogen derived from the atmosphere (%Ndfa) in herbage from four birdsfoot trefoil cultivars grown in two different years

<table>
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<tr>
<th>Year</th>
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<th>Cultivar^a</th>
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<th>FER</th>
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^aAPBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

^bH = harvest.

^cAVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

^dLSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 3. Percentage N derived from the atmosphere in four different birdsfoot trefoil cultivars grown in mixed stands with orchardgrass in 1989. LSD = least significant difference, P<0.05 (NS = no significant main effect)
Figure 4. Percentage N derived from the atmosphere in four different birdsfoot trefoil cultivars grown in mixed stands with orchardgrass 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
proportion in the BT mixtures for 1990 (Table 3). Regressions usually were not significant \((P \leq 0.05)\) for either year.

Values of FNY ranged from 13.4 to 78.9 kg ha\(^{-1}\) over three harvests in 1989 (Table 6). Fixed-N yields for all cultivars were always highest in H1 and decreased over time (Figure 5). No differences were shown among cultivars in any harvest. Total-season FNYs ranged from 96.6 to 138.0 kg ha\(^{-1}\), with Norcen yielding the most fixed-N and APB-8701 the least. Differences in total-season FNY were nonsignificant \((P \leq 0.05)\), however.

Fixed-N yields in 1990 ranged from 13.1 to 55.4 kg ha\(^{-1}\) over three harvests (Table 6). Values of FNY for all cultivars were always highest in H1 and decreased over time (Figure 6). No differences were shown among cultivars in the first two harvests. In H3, Fergus had a greater \((P \leq 0.05)\) yield of fixed-N than APB-8701. Total-season FNYs ranged from 90 to 108 kg ha\(^{-1}\), with Fergus yielding the most fixed-N and APB-8701 the least, although these differences were nonsignificant \((P \leq 0.05)\). Fixed-N yields for both years tended to be related positively to legume proportion in the mixtures (Table 3). Regressions usually were not significant \((P \leq 0.05)\) for either year.
Table 6. Yield of fixed-nitrogen in herbage from four cultivars of birdsfoot trefoil grown in two different years

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<tr>
<th>Year</th>
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<th>FER</th>
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^aAPBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

^bH = harvest.

^cAVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

^dLSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.

^eTOT = total-season yield.
Figure 5. Yield of fixed-N from four different cultivars of birdsfoot trefoil grown in mixed stands with orchardgrass in 1989. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Figure 6. Yield of fixed-N from four different cultivars of birdsfoot trefoil grown in mixed stands with orchardgrass in 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Transfer of fixed-N to associated orchardgrass

Values of $\%$Ngdfa ranged from 1.9 to 26.3% over three harvests in 1989 (Table 7). Nitrogen transfer was strongly influenced by harvest date, however, there were no differences ($P \leq 0.05$) shown among cultivars in any harvest (Figure 7). When averaged over three harvests, OG grown with APB-8701 (OG-APB) derived the least amount of N from the atmosphere (7.8%) and OG grown with Norcen (OG-NOR) derived the greatest amount (15.0%). Differences in mean $\%$Ngdfa for 1989 were not significant ($P \leq 0.05$). Total-season (average of all cultivars and all harvests) $\%$Ngdfa was 11.7%, i.e., in 1989 approximately 12% of the N in associated OG came from fixation.

Values of $\%$Ngdfa in 1990 ranged from 33.7 to 52.1% over three harvests (Table 7). There were no differences ($P \leq 0.05$) shown among cultivars in any harvest (Figure 8). When averaged over three harvests, OG grown with Fergus (OG-FER) derived the least amount of N from the atmosphere (38.7%) and OG-NOR derived the greatest amount (46.4%). Differences in mean $\%$Ngdfa for 1990 were not significant ($P \leq 0.05$). Total-season $\%$Ngdfa was 41.9%, i.e., in 1990 approximately 42% of the N in associated OG came from fixation. In both 1989 and 1990, all mixtures except DWN-OG showed a negative relationship between $\%$Ngdfa and legume proportion (Table 3). Regressions were not significant ($P \leq 0.05$) for either year.
Table 7. Percentage nitrogen derived from the atmosphere in orchardgrass (%Ngdfa) grown in association with four cultivars of birdsfoot trefoil in two different years

<table>
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<tr>
<th>Year</th>
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<th>APBT</th>
<th>DWN</th>
<th>FER</th>
<th>NOR</th>
<th>AVG&lt;sup&gt;c&lt;/sup&gt;</th>
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<sup>a</sup>APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 7. Percentage harvested-N in orchardgrass derived from the atmosphere when grown with each respective birdsfoot trefoil cultivar in 1989. LSD = least significant difference, $P \leq 0.05$ (NS = no significant main effect)
Figure 8. Percentage harvested-N in orchardgrass derived from the atmosphere when grown with each respective birdsfoot trefoil cultivar 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Values of TNY ranged from 0.3 to 4.7 kg ha$^{-1}$ over three harvests in 1989 (Table 8). Transferred-N yield usually was lowest in H2, although no differences (P≤0.05) were shown among any of the cultivars in any of the harvests (Figure 9). When averaged over three harvests, OG-APB had the least TNY (1.4 kg ha$^{-1}$) and OG grown with Dawn (OG-DWN) had the greatest (2.6 kg ha$^{-1}$), although differences in mean TNY were not significant (P≤0.05). Total-season TNYs ranged from 4.2 to 7.7 kg ha$^{-1}$ with OG-DWN yielding the greatest amount of transferred-N and OG-APB yielding the least. Differences in total-season TNY were not significant (P≤0.05), however.

Transferred-N yields in 1990 ranged from 6.3 to 17.9 kg ha$^{-1}$ over three harvests (Table 8). No differences (P≤0.05) were shown among any of the cultivars in any of the harvests (Figure 10). When averaged over three harvests, OG-FER had the lowest TNY (10.4 kg ha$^{-1}$) and OG-DWN had the highest (14.0 kg ha$^{-1}$), although differences in mean TNY were not significant (P≤0.05). Total-season TNYs ranged from 31.3 to 41.8 kg ha$^{-1}$ with OG-DWN yielding the greatest amount of transferred-N and OG-FER yielding the least, although differences in total-season TNY were not significant (P≤0.05). This is a six-fold (average) increase in total-season TNY for 1990 as compared to 1989. Transferred-N yields were related positively to legume proportion for all mixtures except NOR-OG in 1989, however, TNYs were related negatively to legume proportion.
Table 8. Yield of transferred-nitrogen in herbage from orchardgrass grown in association with four cultivars of birdsfoot trefoil in two different years

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<th>Year</th>
<th>H&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Cultivar&lt;sup&gt;a&lt;/sup&gt;</th>
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<td></td>
<td>TOT&lt;sup&gt;e&lt;/sup&gt;</td>
<td>34.2</td>
<td>41.8</td>
<td>31.3</td>
<td>39.7</td>
<td>36.8</td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.

<sup>e</sup>TOT = total-season yield.
Figure 9. Yield of transferred-N in orchardgrass when grown with each respective birdsfoot trefoil cultivar in 1989. LSD = least significant difference, P ≤ 0.05 (NS = no significant main effect)
Figure 10. Yield of transferred-N in orchardgrass when grown with each respective birdsfoot trefoil cultivar 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
proportions for all mixtures in 1990 (Table 3). Regressions were not significant (P<0.05) for any of the mixtures in either year.

Red clover dry matter yield

Total-season DM yields in 1989 ranged from 4.4 to 6.3 Mg ha\(^{-1}\) (Table 9). Dry matter yields in H1 exceeded 3.0 Mg ha\(^{-1}\), while DM yields in H3 were 1.0 Mg ha\(^{-1}\) or less (Figure 11). Yields were always greatest in H1 and decreased over time. Dry matter yields of the four mixtures differed (P<0.05) in H2 and H3 only. In H2 and H3, the Mammoth mixture (MAM-OG) yielded significantly (P<0.05) less herbage DM than the other mixtures. In all three harvests, the Redland II mixture (RII-OG) had the greatest DM yields of the four mixtures, although differences were not always significant (P<0.05).

Total-season DM yields in 1990 ranged from 6.7 to 9.6 Mg ha\(^{-1}\) (Table 9), an increase of up to 44% over 1989. Dry matter yields always were greatest in H1 and decreased over time (Figure 12). Dry matter yields for H1 ranged from 3.6 to 4.4 Mg ha\(^{-1}\), and were up to 25% greater than DM yields for H1 in 1989. Dry matter yields for H2 were as much as 58% greater than DM yields for H2 in 1989 while H3 of 1990 yielded up to 79% more DM than H3 of 1989. The APR-8701 mixture (APR-OG), the Arlington mixture (ARL-OG), and RII-OG were all
Table 9. Herbage dry matter yield of four red clover/orchardgrass mixtures grown in two different years

<table>
<thead>
<tr>
<th>Year</th>
<th>H&lt;sup&gt;b&lt;/sup&gt;</th>
<th>APRC</th>
<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>AVG&lt;sup&gt;c&lt;/sup&gt;</th>
<th>LSD&lt;sup&gt;d&lt;/sup&gt;</th>
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<td>0.2</td>
</tr>
<tr>
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<td>AVG</td>
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<td>1.8</td>
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<tr>
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<td>3.6</td>
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<td>2.8</td>
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<td>0.6</td>
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<tr>
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<td>TOT&lt;sup&gt;e&lt;/sup&gt;</td>
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<td>9.0</td>
<td>6.7</td>
<td>8.8</td>
<td>8.5</td>
<td>1.1</td>
</tr>
</tbody>
</table>

<sup>a</sup>APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.

<sup>e</sup>TOT = total-season yield.
Figure 11. Herbage dry matter yields from three harvests of four red clover/orchardgrass mixtures grown in 1989. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, \( P \leq 0.05 \) (NS = no significant main effect)
Figure 12. Herbage dry matter yields from three harvests of four red clover/orchardgrass mixtures grown 1990. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, $P \leq 0.05$ (NS = no significant main effect)
significantly greater (P≤0.05) than MAM-OG in DM yields for all three harvests as well as for total-season DM yield.

Mean RC DM yields were related positively to legume proportion in the mixtures for both years (Table 10). Regressions usually were not significant (P≤0.05) for 1989. Regressions did differ for all mixtures except ARL-OG for 1990, however. Legume proportions for 1989 were usually greater than 60% for all mixtures in all harvests and averaged more than 70% for the entire growing season (Table 11). Legume proportions were highest for all mixtures in H1. When averaged over three harvests, Mammoth maintained the lowest legume proportion in the mixture (66.7%). Legume proportions for 1990 were usually less than 55% for all mixtures in all harvests and averaged nearly 40% over the entire 1990 growing season (Table 11). When averaged over three harvests, APR-8701 maintained the greatest legume proportion (47.5%) and Mammoth had the least (31.2%). Legume proportions were always lower in 1990, however, differences were not always significant (P≤0.05).

_\text{N}_2 \text{ fixation by red clover}_

Values of %Ndfa for RC cultivars ranged from 94.0 to 99.3% over three harvests in 1989 (Table 12). Values of %Ndfa for all cultivars were highest in H1 and tended to decrease over time (Figure 13). Lowest values for all
Table 10. Regression equations of dry matter yield (DM), N₂ fixation (%Ndfa), fixed-N yield (FNY), N transfer (%Ngdfa), and transferred-N yield (TNY) on percentage legume in four red clover/orchardgrass mixtures.

<table>
<thead>
<tr>
<th>CV^a</th>
<th>VAR^b</th>
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<td></td>
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<td>SE^c</td>
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</tr>
<tr>
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<td></td>
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<td>1990</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>APRC</td>
<td>DM</td>
<td>-1.6 + 0.04X</td>
<td>0.13</td>
<td>NS</td>
<td>0.9 + 0.05X</td>
<td>0.54</td>
<td>0.7</td>
</tr>
<tr>
<td>ARL</td>
<td>DM</td>
<td>0.6 + 0.02X</td>
<td>0.02</td>
<td>NS</td>
<td>1.5 + 0.03X</td>
<td>0.23</td>
<td>NS</td>
</tr>
<tr>
<td>MAM</td>
<td>DM</td>
<td>-1.4 + 0.04X</td>
<td>0.21</td>
<td>NS</td>
<td>0.8 + 0.05X</td>
<td>0.77</td>
<td>0.5</td>
</tr>
<tr>
<td>RII</td>
<td>DM</td>
<td>-4.3 + 0.09X</td>
<td>0.40</td>
<td>1.0</td>
<td>0.7 + 0.06X</td>
<td>0.45</td>
<td>0.8</td>
</tr>
<tr>
<td>APRC</td>
<td>%Ndfa</td>
<td>94.9 + 0.02X</td>
<td>0.27</td>
<td>NS</td>
<td>97.2 + 0.02X</td>
<td>0.08</td>
<td>NS</td>
</tr>
<tr>
<td>ARL</td>
<td>%Ndfa</td>
<td>110.8 - 0.19X</td>
<td>0.52</td>
<td>NS</td>
<td>100.0 - 0.05X</td>
<td>0.17</td>
<td>NS</td>
</tr>
<tr>
<td>MAM</td>
<td>%Ndfa</td>
<td>92.2 + 0.06X</td>
<td>0.12</td>
<td>NS</td>
<td>97.6 + 0.01X</td>
<td>0.05</td>
<td>NS</td>
</tr>
<tr>
<td>RII</td>
<td>%Ndfa</td>
<td>87.4 + 0.13X</td>
<td>0.26</td>
<td>NS</td>
<td>99.1 - 0.04X</td>
<td>0.02</td>
<td>NS</td>
</tr>
<tr>
<td>APRC</td>
<td>FNY</td>
<td>-67.8 + 1.57X</td>
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<td>NS</td>
<td>-26.5 + 1.38X</td>
<td>0.71</td>
<td>13.0</td>
</tr>
<tr>
<td>ARL</td>
<td>FNY</td>
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<td>-19.7 + 1.21X</td>
<td>0.60</td>
<td>16.1</td>
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<tr>
<td>MAM</td>
<td>FNY</td>
<td>-43.6 + 1.36X</td>
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<td>27.8</td>
<td>-13.0 + 1.22X</td>
<td>0.85</td>
<td>10.4</td>
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<tr>
<td>RII</td>
<td>FNY</td>
<td>-189.7 + 3.36X</td>
<td>0.62</td>
<td>23.3</td>
<td>-21.9 + 1.32X</td>
<td>0.81</td>
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</tr>
<tr>
<td>APRC</td>
<td>%Ngdfa</td>
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<td>0.01</td>
<td>NS</td>
<td>81.7 - 0.23X</td>
<td>0.25</td>
<td>NS</td>
</tr>
<tr>
<td>ARL</td>
<td>%Ngdfa</td>
<td>15.7 + 0.38X</td>
<td>0.03</td>
<td>NS</td>
<td>69.4 - 0.02X</td>
<td>0.00</td>
<td>NS</td>
</tr>
<tr>
<td>MAM</td>
<td>%Ngdfa</td>
<td>5.4 + 0.57X</td>
<td>0.12</td>
<td>NS</td>
<td>60.2 + 0.18X</td>
<td>0.06</td>
<td>NS</td>
</tr>
<tr>
<td>RII</td>
<td>%Ngdfa</td>
<td>-91.2 + 1.93X</td>
<td>0.40</td>
<td>20.7</td>
<td>81.8 - 0.35X</td>
<td>0.32</td>
<td>NS</td>
</tr>
<tr>
<td>APRC</td>
<td>TNY</td>
<td>7.7 - 0.03X</td>
<td>0.00</td>
<td>NS</td>
<td>26.3 - 0.14X</td>
<td>0.08</td>
<td>NS</td>
</tr>
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<td>ARL</td>
<td>TNY</td>
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<td>0.05</td>
<td>NS</td>
<td>24.9 - 0.13X</td>
<td>0.10</td>
<td>NS</td>
</tr>
<tr>
<td>MAM</td>
<td>TNY</td>
<td>3.3 + 0.04X</td>
<td>0.02</td>
<td>NS</td>
<td>15.5 + 0.07X</td>
<td>0.03</td>
<td>NS</td>
</tr>
<tr>
<td>RII</td>
<td>TNY</td>
<td>-14.1 + 0.28X</td>
<td>0.34</td>
<td>3.4</td>
<td>17.3 + 0.10X</td>
<td>0.02</td>
<td>NS</td>
</tr>
</tbody>
</table>

^aCV = cultivar.

^bVAR = response variable; DM in Mg ha⁻¹, FNY and TNY in kg ha⁻¹.

^cSE = square root of the residual mean square; NS = no significant main effect (P≤0.05).
Table 11. Legume proportion of four red clover/orchardgrass mixtures grown in two different years

<table>
<thead>
<tr>
<th>Year</th>
<th>H&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Cultivar&lt;sup&gt;a&lt;/sup&gt;</th>
<th>APRC</th>
<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>AVG&lt;sup&gt;c&lt;/sup&gt;</th>
<th>LSD&lt;sup&gt;d&lt;/sup&gt;</th>
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</thead>
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<td>1</td>
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<td>81.0</td>
<td>77.9</td>
<td>75.9</td>
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<td>78.8</td>
<td>NS</td>
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<td>73.1</td>
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<sup>a</sup>APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P < 0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Table 12. Percentage nitrogen derived from the atmosphere (%Ndfa) in herbage from four red clover cultivars grown in two different years

<table>
<thead>
<tr>
<th>Year</th>
<th>H^b</th>
<th>Cultivar^a</th>
<th>APRC</th>
<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>AVG^c</th>
<th>LSD^d</th>
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<td></td>
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<td>99.1</td>
<td>0.4</td>
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</tr>
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<td>95.2</td>
<td>94.0</td>
<td>94.7</td>
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</tr>
<tr>
<td></td>
<td>AVG</td>
<td>96.7</td>
<td>96.4</td>
<td>96.4</td>
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<td>96.5</td>
<td>NS</td>
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<tr>
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<td>LSD</td>
<td>1.6</td>
<td>NS</td>
<td>2.6</td>
<td>2.0</td>
<td>1.4</td>
<td></td>
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</tr>
<tr>
<td>1990</td>
<td>1</td>
<td>99.3</td>
<td>98.6</td>
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<td>NS</td>
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</table>

^aAPRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

^bH = harvest.

^cAVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

^dLSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 13. Percentage N derived from the atmosphere in four different red clover cultivars grown in mixed stands with orchardgrass in 1989. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
cultivars except Arlington were observed in H3. APR-8701 had greater (P≤0.05) %Ndfa than Redland II only in H1. When averaged over the three harvests, APR-8701 and Redland II had the greatest %Ndfa (96.7%) and Arlington and Mammoth had the least (96.4%), although differences in mean %Ndfa were not significant (P≤0.05). Total-season %Ndfa was 96.5%, i.e., in 1989 over 95% of the N in RC came from fixation.

Values for %Ndfa for the four cultivars in 1990 ranged from 95.7 to 99.4% over three harvests (Table 12). Values of %Ndfa for all cultivars were highest in H1 and lowest in H2 (Figure 14). There were no differences (P≤0.05) observed among cultivars in any of the three harvests. When averaged over the three harvests, APR-8701 had the greatest %Ndfa (98.2%) and Arlington had the least (97.5%). Differences in mean %Ndfa were not significant (P≤0.05). Total-season %Ndfa was 97.9%, i.e., in 1990 almost 98% of the N in RC came from fixation. Percentage Ndfa tended to be related positively to legume proportion in the mixtures for both years (Table 10). Arlington, however, showed negative relationships in both years. Regressions were not significant (P≤0.05) for either year.

Values of FNY ranged from 19.5 to 99.7 kg ha⁻¹ over three harvests in 1989 (Table 13). Fixed-N yields for all cultivars were always highest in H1 and decreased over time (Figure 15). In H1, Redland II yielded more (P≤0.05) fixed-N than
Figure 14. Percentage N derived from the atmosphere in four different red clover cultivars grown in mixed stands with orchardgrass 1990. LSD = least significant difference, \( P \leq 0.05 \) (NS = no significant main effect)
Table 13. Yield of fixed-nitrogen in herbage from four cultivars of red clover grown in two different years

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<th>Year</th>
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<th>MAM</th>
<th>RII</th>
<th>AVG&lt;sup&gt;c&lt;/sup&gt;</th>
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<sup>a</sup>APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.

<sup>e</sup>TOT = total-season yield.
Figure 15. Yield of fixed-N from four different cultivars of red clover grown in mixed stands with orchardgrass in 1989. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Arlington. No differences were shown among cultivars in H2 or H3. Total-season FNYs in 1989 ranged from 140.3 to 159.2 kg ha\(^{-1}\) with APR-8701 yielding the greatest amount of fixed-N and Mammoth yielding the least. No differences (P<0.05) were shown among any of the cultivars in total-season FNY, however.

Values of FNY in 1990 ranged from 8.2 to 64.6 kg ha\(^{-1}\) over three harvests (Table 13). Fixed-N yields for all cultivars were always highest in H1 and decreased over time (Figure 16). No differences were shown among cultivars in H1. In H2, APR-8701 and Arlington had greater (P<0.05) yields of fixed-N than Mammoth. In H3, APR-8701 yielded more (P<0.05) fixed-N than Redland II and Mammoth. Total-season FNYs in third-year swards ranged from 72.6 to 116.6 kg ha\(^{-1}\) with APR-8701 and Arlington yielding greater (P<0.05) amounts of fixed-N for the season than Mammoth and Redland II. Fixed-N yields were related positively to legume proportion in the mixtures for both years (Table 10). Regressions were significant (P<0.05) for all cultivars in both years except for APR-8701 and Arlington in 1989.

**Transfer of fixed-N to associated orchardgrass**

Values of %Ngdfa ranged from 20.2 to 74.6% over three harvests in 1989 (Table 14). Nitrogen transfer was strongly influenced by harvest date, however, there were no differences (P<0.05) shown among cultivars in any harvest (Figure 17).
Figure 16. Yield of fixed-N from four different cultivars of red clover grown in mixed stands with orchardgrass 1990. LSD = least significant difference, P ≤ 0.05 (NS = no significant main effect)
Table 14. Percentage nitrogen derived from the atmosphere in orchardgrass (%Ngdfa) grown in association with four cultivars of red clover in two different years

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<sup>a</sup>APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 17. Percentage harvested-N in orchardgrass derived from the atmosphere when grown with each respective red clover cultivar in 1989. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
When averaged over three harvests, OG grown with Mammoth (OG-MAM) derived the least amount of N from the atmosphere (43.7%) and OG grown with Redland II (OG-RII) derived the greatest amount (48.9%), although differences in mean %Ngdfa were not significant (P<0.05). Total-season %Ngdfa was 45.6%, i.e., in 1989 just under 50% of the N in associated OG came from fixation.

Values of %Ngdfa in 1990 ranged from 62.6 to 73.5% over three harvests (Table 14). There were no differences (P≤0.05) shown among cultivars in any harvest (Figure 18). When averaged over three harvests, OG-MAM derived the least amount of N from the atmosphere (65.9%) and OG grown with APR-8701 (OG-APR) derived the greatest amount (70.5%). Differences in mean %Ngdfa were not significant (P<0.05). Total-season %Ngdfa was 68.6%, i.e., in 1990 nearly 70% of the N in associated OG came from fixation. Total-season %Ngdfa was 1.5 times greater for 1990 than for 1989. Positive relationships between %Ngdfa and legume proportion in the mixtures were shown for all four RC cultivars in 1989, however, only MAM-OG showed a positive relationship in 1990 (Table 10). Regressions usually were not significant (P≤0.05) in either year.

Values of TNY ranged from 2.1 to 11.2 kg ha⁻¹ over three harvests in 1989 (Table 15). Transferred-N yield usually was lowest in H2, although no differences were shown among any of
Figure 18. Percentage harvested-N in orchardgrass derived from the atmosphere when grown with each respective red clover cultivar 1990. LSD = least significant difference, P<0.05 (NS = no significant main effect)
Table 15. Yield of transferred-nitrogen in herbage from orchardgrass grown in association with four cultivars of red clover in two different years

<table>
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<tr>
<th>Year</th>
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<th>Cultivar&lt;sup&gt;a&lt;/sup&gt;</th>
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<sup>a</sup>APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.

<sup>e</sup>TOT = total-season yield.
the cultivars in any of the harvests (Figure 19). When averaged over three harvests, OG-APR had the lowest TNY (5.2 kg ha\(^{-1}\)) and OG-MAM and OG-RII had the highest (5.9 kg ha\(^{-1}\)). These differences were not significant (P≤0.05). Total-season TNYs ranged from 15.7 to 17.7 kg ha\(^{-1}\) with OG-MAM yielding the greatest amount of transferred-N and OG-APR yielding the least. Differences in total-season TNY were not significant (P≤0.05).

Transferred-N yields in 1990 ranged from 14.8 to 23.8 kg ha\(^{-1}\) over three harvests (Table 15). No differences (P≤0.05) were shown among any of the cultivars in any of the harvests (Figure 20). When averaged over three harvests, OG-MAM had the lowest TNY (17.6 kg ha\(^{-1}\)) and OG-RII had the highest (20.7 kg ha\(^{-1}\)), however, these differences were not significant (P≤0.05). Total-season TNYs ranged from 53.0 to 62.0 kg ha\(^{-1}\) with OG-RII yielding the greatest amount of transferred-N and OG-MAM yielding the least, although differences were not significant (P≤0.05). Negative relationships between TNY and legume proportion in the mixtures were shown for both APR-OG and ARL-OG in 1989 and 1990 (Table 10), however, regressions usually were not significant (P≤0.05).
Figure 19. Yield of transferred-N in orchardgrass when grown with each respective red clover cultivar in 1989. LSD = least significant difference, P<0.05 (NS = no significant main effect)
Figure 20. Yield of transferred-N in orchardgrass when grown with each respective red clover cultivar 1990. LSD = least significant difference, $P \leq 0.05$ (NS = no significant main effect)
Experiment Two

Birdsfoot trefoil dry matter yield

Three-cut system  Dry matter yields for both years were always greatest in H1 and decreased over time. Yields for H1 in 1990 exceeded 4.5 Mg ha\(^{-1}\) while DM yields in H3 were 2.7 Mg ha\(^{-1}\) or less (Figure 21). Harvest differences were shown for all mixtures except FER-OG (Table 16). In H1, DWN-OG had a greater (P≤0.05) yield of herbage DM than APB-OG. In H2, APB-OG had a greater (P≤0.05) yield of herbage DM than DWN-OG, while in H3, DWN-OG yielded more DM than FER-OG. When averaged over three harvests, DWN-OG yielded more (P≤0.05) herbage DM than FER-OG (Table 16).

Dry matter yields for H1 in 1991 exceeded 4.2 Mg ha\(^{-1}\) while DM yields in H3 were 1.7 Mg ha\(^{-1}\) or less (Figure 22). Harvest differences were shown for all mixtures (Table 16). In H1, DWN-OG and NOR-OG had greater (P≤0.05) yields of herbage DM than APB-OG. In H3, DWN-OG, FER-OG, and NOR-OG all yielded more (P≤0.05) herbage DM than APB-OG. There were no differences shown among cultivars in H2. When averaged over three harvests, DWN-OG and FER-OG yielded more (P≤0.05) herbage DM than APB-OG (Table 16).

Six-cut system  Dry matter yields for both years were always greatest in H1 and tended to decrease with time. Herbage DM yields for 1990 ranged from 0.6 to 1.6 Mg ha\(^{-1}\)
Figure 21. Herbage dry matter yields from four birdsfoot trefoil/orchardgrass mixtures managed under a 3-cut system in 1990. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 16. Herbage dry matter yield of four birdsfoot trefoil/orchardgrass mixtures managed under a 3-cut system for two years

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^a APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

^b H = harvest.

^c AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

^d LSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 22. Herbage dry matter yields from four birdsfoot trefoil/orchardgrass mixtures managed under a 3-cut system in 1991. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
(Figure 23). Harvest differences were shown for all mixtures, although not necessarily among all harvests (Table 17). In harvests where differences among mixtures were significant ($P<0.05$), NOR-OG usually had the greatest ($P<0.05$) yield of herbage DM and FER-OG usually had the least. When averaged over six harvests, no differences ($P<0.05$) were shown among mixtures (Table 17).

Dry matter yields for 1991 ranged from 0.4 to 1.9 Mg ha$^{-1}$ (Figure 24). Harvest differences were shown for all mixtures, although not necessarily among all harvests (Table 17). In harvests where differences among mixtures were significant ($P<0.05$), NOR-OG usually had the greatest ($P<0.05$) yield of herbage DM and APB-OG usually had the least. When averaged over six harvests, APB-OG yielded the least ($P<0.05$) amount of herbage DM of the four mixtures (Table 17).

**Total-season DM yield**

Total-season DM yields in 1990 ranged from 8.7 to 10.1 and 6.2 to 6.8 Mg ha$^{-1}$ for the 3-cut and 6-cut systems, respectively (Figure 25). Under both harvest management systems, DWN-OG and NOR-OG yielded more ($P<0.05$) total DM than FER-OG. For all mixtures, the 3-cut system yielded a significantly greater ($P<0.05$) amount of total herbage DM than the 6-cut system (Table 18). Six-cut system DM yields were as much as 33% lower than DM yields from the 3-cut system.

Total-season DM yields in 1991 ranged from 7.3 to 8.6 and
Figure 23. Herbage dry matter yields from four birdsfoot trefoil/orchardgrass mixtures managed under a 6-cut system in 1990. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 17. Herbage dry matter yield of four birdsfoot trefoil/orchardgrass mixtures managed under a 6-cut system for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>H</th>
<th>APBT</th>
<th>DWN</th>
<th>FER</th>
<th>NOR</th>
<th>AVG</th>
<th>LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
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</tr>
<tr>
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</tr>
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<td>1.0</td>
<td>1.1</td>
<td>1.1</td>
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<td>1.2</td>
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<td>1.0</td>
<td>0.9</td>
<td>1.0</td>
<td>NS</td>
</tr>
<tr>
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<td>1.0</td>
<td>1.1</td>
<td>1.1</td>
<td>NS</td>
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<tr>
<td>1991</td>
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<td>1.7</td>
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<td>1.9</td>
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<td>NS</td>
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<td>1.5</td>
<td>0.1</td>
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<tr>
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<td>0.1</td>
</tr>
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<td>0.8</td>
<td>0.7</td>
<td>0.8</td>
<td>0.1</td>
</tr>
<tr>
<td>AVG</td>
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<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
<td>1.0</td>
<td>0.1</td>
</tr>
<tr>
<td>LSD</td>
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<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
<td>0.1</td>
<td></td>
</tr>
</tbody>
</table>

aAPBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

bH = harvest.

cAVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

dLSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 24. Herbage dry matter yields from four birdsfoot trefoil/orchardgrass mixtures managed under a 6-cut system in 1991. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Figure 25. Total-season herbage dry matter yields from four birdsfoot trefoil/orchardgrass mixtures managed under 3- and 6-cut systems in 1990. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 18. Total-season herbage dry matter yield of four birdsfoot trefoil/orchardgrass mixtures managed under two different harvest intensities for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>Mgt</th>
<th>APBT</th>
<th>DWN</th>
<th>FER</th>
<th>NOR</th>
<th>LSD</th>
</tr>
</thead>
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<td>10.1</td>
<td>8.7</td>
<td>9.9</td>
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<tr>
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<td>B</td>
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<td>6.8</td>
<td>6.2</td>
<td>6.9</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>LSD</td>
<td>1.0</td>
<td>0.7</td>
<td>1.2</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>A</td>
<td>7.3</td>
<td>8.6</td>
<td>8.4</td>
<td>8.2</td>
<td>1.1</td>
</tr>
<tr>
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<td>B</td>
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<td>6.5</td>
<td>6.8</td>
<td>6.4</td>
<td>0.7</td>
</tr>
<tr>
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<td>LSD</td>
<td>1.2</td>
<td>0.7</td>
<td>1.0</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>

\(^{a}\)APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

\(^{b}\)Mgt = harvest management. A = 3-cut system; B = 6-cut system.

\(^{c}\)LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
5.6 to 6.8 Mg ha\(^{-1}\) for the 3-cut and 6-cut systems, respectively (Figure 26). Under the 3-cut system, DWN-OG yielded more (P\leq 0.05) total herbage DM than APB-OG. Under the 6-cut system, APB-OG yielded significantly less (P\leq 0.05) total herbage DM than any of the other mixtures. For all mixtures, the 3-cut system yielded a significantly greater (P\leq 0.05) amount of total herbage DM than the 6-cut system (Table 18). Six-cut system DM yields were as much as 24% lower than DM yields from the 3-cut system.

Legume proportions for the 3-cut system ranged from 26.8 to 87.0 and 30.0 to 58.9% for 1990 and 1991, respectively (Table 19). For the 3-cut system in 1990, Fergus maintained the highest (P\leq 0.05) mean legume proportion in the mixture (74.4%) and APB-8701 had the lowest (57.0%). For 1991 (3-cut system), Norcen maintained the greatest (P\leq 0.05) mean legume proportion in the mixture (52.0%), while APB-8701 had the least (40.3%) (Table 19). Mean BT DM yields for the 3-cut system tended to be related positively to legume proportion in the mixtures for both years (Table 20). Regressions usually were not significant (P\leq 0.05) for either year, however.

Legume proportions for the 6-cut system ranged from 31.7 to 85.8 and 25.4 to 61.0% for 1990 and 1991, respectively (Table 21). For the 6-cut system in 1990, Fergus maintained the highest (P\leq 0.05) mean legume proportion in the mixture (72.8%) and APB-8701 had the lowest (60.7%). Likewise, for
Figure 26. Total-season herbage dry matter yields from four birdsfoot trefoil/orchardgrass mixtures managed under 3- and 6-cut systems in 1991. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 19. Legume proportion of four birdsfoot trefoil/orchardgrass mixtures managed under a 3-cut system for two different years

<table>
<thead>
<tr>
<th>Year</th>
<th>H\textsuperscript{b}</th>
<th>Cultivar\textsuperscript{a}</th>
<th>APBT</th>
<th>DWN</th>
<th>FER</th>
<th>NOR</th>
<th>AVG\textsuperscript{c}</th>
<th>LSD\textsuperscript{d}</th>
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<tbody>
<tr>
<td>1990</td>
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<td>77.3</td>
<td>85.1</td>
<td>87.0</td>
<td>79.0</td>
<td>82.1</td>
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<tr>
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<td>2</td>
<td>66.8</td>
<td>73.4</td>
<td>78.0</td>
<td>68.8</td>
<td>71.8</td>
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</tr>
<tr>
<td></td>
<td>3</td>
<td>26.8</td>
<td>48.6</td>
<td>58.4</td>
<td>38.9</td>
<td>43.2</td>
<td>16.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AVG</td>
<td>57.0</td>
<td>69.0</td>
<td>74.4</td>
<td>62.2</td>
<td>65.7</td>
<td>7.0</td>
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</tr>
<tr>
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<td>LSD</td>
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<td>12.4</td>
<td>14.5</td>
<td>13.4</td>
<td>6.1</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>46.5</td>
<td>52.9</td>
<td>46.1</td>
<td>58.9</td>
<td>51.1</td>
<td>NS</td>
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<td>30.0</td>
<td>34.3</td>
<td>40.7</td>
<td>46.6</td>
<td>37.9</td>
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<td>56.8</td>
<td>56.8</td>
<td>50.6</td>
<td>52.2</td>
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</tr>
<tr>
<td></td>
<td>AVG</td>
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<td>48.0</td>
<td>47.8</td>
<td>52.0</td>
<td>47.1</td>
<td>9.2</td>
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</tr>
<tr>
<td></td>
<td>LSD</td>
<td>NS</td>
<td>22.1</td>
<td>11.7</td>
<td>NS</td>
<td>8.0</td>
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</tr>
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</table>

\textsuperscript{a}APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

\textsuperscript{b}H = harvest.

\textsuperscript{c}AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

\textsuperscript{d}LSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Table 20. Regression equations of DM yield (DM), N\textsubscript{2} fixation (%N\textsubscript{dfa}), fixed-N yield (FNY), N transfer (%Ng\textsubscript{dfa}), and transferred-N yield (TNY) on percentage legume in four BT/OG mixtures managed under a 3-cut system for two years.

<table>
<thead>
<tr>
<th>CV\textsuperscript{a}</th>
<th>VAR\textsuperscript{b}</th>
<th>1990 Equation</th>
<th>R</th>
<th>SE\textsuperscript{c}</th>
<th>1991 Equation</th>
<th>R</th>
<th>SE</th>
</tr>
</thead>
<tbody>
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<td>APBT DM</td>
<td>4.7 + 0.08X</td>
<td>0.25 NS</td>
<td></td>
<td></td>
<td>5.5 + 0.04X</td>
<td>0.58 NS</td>
<td></td>
</tr>
<tr>
<td>DAWN DM</td>
<td>10.2 - 0.01X</td>
<td>0.00 NS</td>
<td></td>
<td></td>
<td>8.0 + 0.01X</td>
<td>0.29 NS</td>
<td></td>
</tr>
<tr>
<td>FERGUS DM</td>
<td>0.9 + 0.11X</td>
<td>0.63 NS</td>
<td></td>
<td></td>
<td>2.9 + 0.11X</td>
<td>0.80 NS</td>
<td></td>
</tr>
<tr>
<td>NORCEN DM</td>
<td>9.3 + 0.01X</td>
<td>0.11 NS</td>
<td></td>
<td></td>
<td>10.3 - 0.04X</td>
<td>0.55 NS</td>
<td></td>
</tr>
<tr>
<td>APBT %N\textsubscript{dfa}</td>
<td>93.7 + 0.08X</td>
<td>0.36 NS</td>
<td></td>
<td></td>
<td>99.4 - 0.02X</td>
<td>0.43 NS</td>
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</tr>
<tr>
<td>DAWN %N\textsubscript{dfa}</td>
<td>98.0 - 0.01X</td>
<td>0.01 NS</td>
<td></td>
<td></td>
<td>98.0 - 0.01X</td>
<td>0.02 NS</td>
<td></td>
</tr>
<tr>
<td>FERGUS %N\textsubscript{dfa}</td>
<td>104.0 - 0.08X</td>
<td>0.36 NS</td>
<td></td>
<td></td>
<td>101.4 - 0.08X</td>
<td>0.77 NS</td>
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</tr>
<tr>
<td>NORCEN %N\textsubscript{dfa}</td>
<td>67.1 + 0.49X</td>
<td>0.82 NS</td>
<td></td>
<td></td>
<td>97.6 + 0.01X</td>
<td>0.15 NS</td>
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</tr>
<tr>
<td>APBT FNY</td>
<td>175.2 - 0.56X</td>
<td>0.04 NS</td>
<td></td>
<td></td>
<td>-9.1 + 2.11X</td>
<td>0.79 NS</td>
<td></td>
</tr>
<tr>
<td>DAWN FNY</td>
<td>-394.0 + 8.66X</td>
<td>0.66 NS</td>
<td></td>
<td></td>
<td>8.5 + 1.91X</td>
<td>0.93 NS</td>
<td></td>
</tr>
<tr>
<td>FERGUS FNY</td>
<td>-140.7 + 4.40X</td>
<td>0.99 3.6</td>
<td></td>
<td></td>
<td>-70.6 + 3.42X</td>
<td>0.91 NS</td>
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</tr>
<tr>
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<td></td>
<td></td>
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<td>0.58 NS</td>
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</tr>
<tr>
<td>APBT %Ng\textsubscript{dfa}</td>
<td>-200.1 + 4.24X</td>
<td>0.61 NS</td>
<td></td>
<td></td>
<td>72.8 - 0.77X</td>
<td>0.72 NS</td>
<td></td>
</tr>
<tr>
<td>DAWN %Ng\textsubscript{dfa}</td>
<td>-171.1 + 3.10X</td>
<td>0.78 NS</td>
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<td></td>
<td>72.5 - 0.56X</td>
<td>0.92 NS</td>
<td></td>
</tr>
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<td>FERGUS %Ng\textsubscript{dfa}</td>
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<td>0.98 2.7</td>
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<td>67.6 - 0.54X</td>
<td>0.24 NS</td>
<td></td>
</tr>
<tr>
<td>NORCEN %Ng\textsubscript{dfa}</td>
<td>329.4 - 4.54X</td>
<td>0.63 NS</td>
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<td>63.6 - 0.45X</td>
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<td>0.74 NS</td>
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<tr>
<td>DAWN TNY</td>
<td>-65.6 + 1.27X</td>
<td>0.58 NS</td>
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<td></td>
<td>68.8 - 0.78X</td>
<td>0.91 NS</td>
<td></td>
</tr>
<tr>
<td>FERGUS TNY</td>
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<td>0.98 0.8</td>
<td></td>
<td></td>
<td>48.7 - 0.41X</td>
<td>0.24 NS</td>
<td></td>
</tr>
<tr>
<td>NORCEN TNY</td>
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<td>0.96 2.0</td>
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<td></td>
<td>72.6 - 0.88X</td>
<td>0.97 2.3</td>
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</tr>
</tbody>
</table>

\textsuperscript{a}CV = cultivar.

\textsuperscript{b}VAR = response variable; DM in Mg ha\textsuperscript{-1}, FNY and TNY in kg ha\textsuperscript{-1}.

\textsuperscript{c}SE = square root of the mean square error; NS = no significant effect (P\leq0.05).
Table 21. Legume proportion of four birdsfoot trefoil/orchardgrass mixtures managed under a 6-cut system for two different years

<table>
<thead>
<tr>
<th>Year</th>
<th>H</th>
<th>APBT</th>
<th>DWN</th>
<th>FER</th>
<th>NOR</th>
<th>AVG°</th>
<th>LSD^</th>
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<td>64.6</td>
<td>64.5</td>
<td>76.4</td>
<td>64.5</td>
<td>67.5</td>
<td>NS</td>
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<td>47.1</td>
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<td>46.4</td>
<td>39.6</td>
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</tr>
<tr>
<td>AVG</td>
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<td>66.9</td>
<td>72.8</td>
<td>64.3</td>
<td>66.2</td>
<td>4.0</td>
</tr>
<tr>
<td>LSD</td>
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<td>11.8</td>
<td>10.0</td>
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<td>32.9</td>
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<td>NS</td>
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</tbody>
</table>

aAPBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.
bH = harvest.
cAVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.
dLSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Table 22. Total-season legume proportion of four birdsfoot trefoil/orchardgrass mixtures managed under two different harvest intensities for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>Mgt(^b)</th>
<th>Cultivar(^a)</th>
<th>APBT</th>
<th>DWN</th>
<th>FER</th>
<th>NOR</th>
<th>LSD(^c)</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
</tr>
<tr>
<td>1990</td>
<td>A</td>
<td>57.0</td>
<td>69.0</td>
<td>74.4</td>
<td>62.2</td>
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<td>B</td>
<td>60.7</td>
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<td>72.8</td>
<td>64.3</td>
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<td>6.7</td>
</tr>
<tr>
<td></td>
<td>LSD</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>1991</td>
<td>A</td>
<td>40.3</td>
<td>48.0</td>
<td>47.9</td>
<td>52.0</td>
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<td>NS</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>36.2</td>
<td>42.2</td>
<td>47.4</td>
<td>44.8</td>
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<td>LSD</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
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</tr>
</tbody>
</table>

\(^a\)APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

\(^b\)Mgt = harvest management. A = 3-cut system; B = 6-cut system.

\(^c\)LSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Table 23. Regression equations of DM yield (DM), N\textsubscript{2} fixation (\%Nd\textsubscript{fa}), fixed-N yield (FNY), N transfer (\%Ng\textsubscript{dfa}), and transferred-N yield (TNY) on percentage legume in four BT/OG mixtures managed under a 6-cut system for two years.

<table>
<thead>
<tr>
<th>CV\textsuperscript{a}</th>
<th>VAR\textsuperscript{b}</th>
<th>1990</th>
<th></th>
<th>1991</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Equation</td>
<td>R</td>
<td>SE\textsuperscript{c}</td>
<td>Equation</td>
<td>R</td>
</tr>
<tr>
<td>APBT</td>
<td>DM</td>
<td>7.5 - 0.02X</td>
<td>0.84</td>
<td>NS</td>
<td>5.4 + 0.01X</td>
</tr>
<tr>
<td>DAWN</td>
<td>DM</td>
<td>4.6 + 0.03X</td>
<td>0.48</td>
<td>NS</td>
<td>5.5 + 0.02X</td>
</tr>
<tr>
<td>FERGUS</td>
<td>DM</td>
<td>5.7 + 0.01X</td>
<td>0.08</td>
<td>NS</td>
<td>5.7 + 0.02X</td>
</tr>
<tr>
<td>NORCEN</td>
<td>DM</td>
<td>4.4 + 0.04X</td>
<td>0.71</td>
<td>NS</td>
<td>4.4 + 0.04X</td>
</tr>
<tr>
<td>APBT</td>
<td>%Nd\textsubscript{fa}</td>
<td>98.4 - 0.05X</td>
<td>0.41</td>
<td>NS</td>
<td>96.8 - 0.01X</td>
</tr>
<tr>
<td>DAWN</td>
<td>%Nd\textsubscript{fa}</td>
<td>94.5 - 0.01X</td>
<td>0.02</td>
<td>NS</td>
<td>99.0 - 0.06X</td>
</tr>
<tr>
<td>FERGUS</td>
<td>%Nd\textsubscript{fa}</td>
<td>70.3 + 0.33X</td>
<td>0.90</td>
<td>NS</td>
<td>96.1 + 0.01X</td>
</tr>
<tr>
<td>NORCEN</td>
<td>%Nd\textsubscript{fa}</td>
<td>101.7 - 0.13X</td>
<td>0.21</td>
<td>NS</td>
<td>97.1 - 0.01X</td>
</tr>
<tr>
<td>APBT</td>
<td>FNY</td>
<td>63.2 + 1.42X</td>
<td>0.83</td>
<td>NS</td>
<td>14.2 + 1.44X</td>
</tr>
<tr>
<td>DAWN</td>
<td>FNY</td>
<td>276.6 - 1.52X</td>
<td>0.50</td>
<td>NS</td>
<td>-53.5 + 3.51X</td>
</tr>
<tr>
<td>FERGUS</td>
<td>FNY</td>
<td>-22.5 + 2.87X</td>
<td>0.56</td>
<td>NS</td>
<td>-148.3 + 5.61X</td>
</tr>
<tr>
<td>NORCEN</td>
<td>FNY</td>
<td>31.1 + 2.23X</td>
<td>0.54</td>
<td>NS</td>
<td>-31.1 + 2.98X</td>
</tr>
<tr>
<td>APBT</td>
<td>%Ng\textsubscript{dfa}</td>
<td>146.0 - 1.42X</td>
<td>0.98</td>
<td>2.1</td>
<td>42.6 - 0.23X</td>
</tr>
<tr>
<td>DAWN</td>
<td>%Ng\textsubscript{dfa}</td>
<td>84.3 - 0.49X</td>
<td>0.37</td>
<td>NS</td>
<td>70.3 - 0.66X</td>
</tr>
<tr>
<td>FERGUS</td>
<td>%Ng\textsubscript{dfa}</td>
<td>53.9 + 0.01X</td>
<td>0.01</td>
<td>NS</td>
<td>52.0 - 0.20X</td>
</tr>
<tr>
<td>NORCEN</td>
<td>%Ng\textsubscript{dfa}</td>
<td>49.9 + 0.07X</td>
<td>0.10</td>
<td>NS</td>
<td>44.0 - 0.16X</td>
</tr>
<tr>
<td>APBT</td>
<td>TNY</td>
<td>156.6 - 1.90X</td>
<td>0.96</td>
<td>4.0</td>
<td>37.5 - 0.41X</td>
</tr>
<tr>
<td>DAWN</td>
<td>TNY</td>
<td>151.9 - 1.71X</td>
<td>0.90</td>
<td>NS</td>
<td>62.0 - 0.74X</td>
</tr>
<tr>
<td>FERGUS</td>
<td>TNY</td>
<td>44.2 - 0.17X</td>
<td>0.06</td>
<td>NS</td>
<td>41.9 - 0.27X</td>
</tr>
<tr>
<td>NORCEN</td>
<td>TNY</td>
<td>46.3 - 0.17X</td>
<td>0.47</td>
<td>NS</td>
<td>37.0 - 0.28X</td>
</tr>
</tbody>
</table>

\textsuperscript{a}CV = cultivar.

\textsuperscript{b}VAR = response variable; DM in Mg ha\textsuperscript{-1}, FNY and TNY in kg ha\textsuperscript{-1}.

\textsuperscript{c}SE = square root of the mean square error; NS = no significant effect (P<0.05).
1991 (6-cut system), Fergus maintained the greatest (P≤0.05) mean legume proportion in the mixture (47.4%), while APB-8701 had the least (36.2%). No differences (P≤0.05) in legume proportion in the mixture were shown between the two management systems for any of the mixtures in either year (Table 22). Mean BT DM yields for the 6-cut system tended to be related positively to legume proportion in the mixtures for both years (Table 23). Regressions usually were not significant (P≤0.05) for either year, however.

\textbf{N\textsubscript{2} fixation by birdsfoot trefoil}

\textbf{Three-cut system} Values of %Ndfa for the four cultivars ranged from 96.0 to 99.1% over three harvests in 1990 (Table 24). Values of %Ndfa were usually highest in H3 and lowest in H2 (Figure 27). Harvest differences (P≤0.05) were shown for all cultivars except Fergus. Cultivars did not differ (P≤0.05) in %Ndfa for any harvest. When averaged over the three harvests, APB-8701 had the greatest %Ndfa (98.0%) and Norcen had the least (97.6%), however, these differences were not significant (P≤0.05) (Table 24).

Values of %Ndfa for the four cultivars in 1991 ranged from 97.3 to 99.0% over three harvests (Table 24). Values of %Ndfa for all cultivars were greatest in H2 and least in H1 (Figure 28). No harvest differences were shown for any of the cultivars except Dawn. In H1, APB-8701 had greater (P≤0.05)
Table 24. Percentage nitrogen derived from the atmosphere (%Ndfa) in herbage from four birdsfoot trefoil cultivars managed under a 3-cut system for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>H&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Cultivar&lt;sup&gt;a&lt;/sup&gt;</th>
<th>APBT</th>
<th>DWN</th>
<th>FER</th>
<th>NOR</th>
<th>AVG&lt;sup&gt;c&lt;/sup&gt;</th>
<th>LSD&lt;sup&gt;d&lt;/sup&gt;</th>
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</thead>
<tbody>
<tr>
<td>1990</td>
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<td>97.7</td>
<td>97.7</td>
<td>97.7</td>
<td>97.9</td>
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<td>97.7</td>
<td>97.6</td>
<td>97.7</td>
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<td>LSD</td>
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<td>NS</td>
<td>2.9</td>
<td>1.0</td>
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<td>97.4</td>
<td>97.3</td>
<td>97.5</td>
<td>97.6</td>
<td>0.7</td>
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<td>99.0</td>
<td>97.4</td>
<td>98.0</td>
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<td>1.2</td>
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<td>97.8</td>
<td>97.6</td>
<td>97.6</td>
<td>97.6</td>
<td>97.9</td>
<td>NS</td>
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<td></td>
<td>AVG</td>
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<td>98.0</td>
<td>97.4</td>
<td>97.7</td>
<td>97.9</td>
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<tr>
<td></td>
<td>LSD</td>
<td>NS</td>
<td>0.7</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>0.5</td>
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</tr>
</tbody>
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<sup>a</sup>APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P ≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 27. Percentage N derived from the atmosphere in four different birdsfoot trefoil cultivars grown in mixed stands with orchardgrass and managed under a 3-cut system in 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Figure 28. Percentage N derived from the atmosphere in four different birdsfoot trefoil cultivars grown in mixed stands with orchardgrass and managed under a 3-cut system in 1991. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
%Ndfa than Fergus. In H2, both APB-8701 and Dawn had greater 
(P<0.05) %Ndfa than Fergus. There were no differences 
(P<0.05) observed among cultivars in H3. When averaged over 
the three harvests, APB-8701 had the greatest (P<0.05) %Ndfa 
(98.6%) and Fergus had the least (97.4%) (Table 24).

Values of FNY ranged from 16.1 to 114.8 kg ha~¹ over 
three harvests in 1990 (Table 25). Fixed-N yields for all 
cultivars were always highest in H1 and decreased over time 
(Figure 29). Harvest differences were shown for all four 
cultivars. No differences were shown among cultivars in H1 
and H2. In H3, both Fergus and Dawn yielded more (P<0.05) 
fixed-N than APB-8701. When averaged over three harvests, 
both Dawn and Fergus yielded more (P<0.05) fixed-N than APB- 
8701 (Table 25).

Fixed-N yields in 1991 ranged from 14.3 to 53.3 kg ha~¹ 
over three harvests (Table 25). Values of FNY for all 
cultivars were always highest in H1 and lowest in H2 (Figure 
30). Harvest differences were shown for all cultivars except 
APB-8701. No differences were shown among cultivars in the 
first two harvests. In H3, APB-8701 yielded less (P<0.05) 
fixed-N than any of the other cultivars. When averaged over 
three harvests, Norcen yielded more (P<0.05) fixed-N than APB- 
8701 (Table 25).

**Six-cut system** Values of %Ndfa for the four cultivars 
ranged from 89.5 to 98.7% over six harvests in 1990 (Table
Table 25. Yield of fixed-nitrogen in herbage from four cultivars of birdsfoot trefoil managed under a 3-cut system for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>H</th>
<th>Cultivar</th>
<th>APBT</th>
<th>DWN</th>
<th>FER</th>
<th>NOR</th>
<th>AVG</th>
<th>LSD</th>
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<td>78.8</td>
<td>114.8</td>
<td>90.8</td>
<td>86.5</td>
<td>92.7</td>
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<td>2</td>
<td>48.0</td>
<td>53.8</td>
<td>56.2</td>
<td>50.0</td>
<td>52.0</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>16.1</td>
<td>35.4</td>
<td>39.8</td>
<td>27.4</td>
<td>29.7</td>
<td>17.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AVG</td>
<td>47.7</td>
<td>68.0</td>
<td>62.3</td>
<td>54.6</td>
<td>58.1</td>
<td>14.3</td>
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<td>LSD</td>
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<td>31.3</td>
<td>22.0</td>
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<td>12.4</td>
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<tr>
<td>1991</td>
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<td>41.6</td>
<td>48.4</td>
<td>38.9</td>
<td>53.3</td>
<td>45.6</td>
<td>NS</td>
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<td>14.3</td>
<td>15.5</td>
<td>17.3</td>
<td>20.9</td>
<td>17.0</td>
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<tr>
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<td>AVG</td>
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<td>33.6</td>
<td>31.1</td>
<td>35.6</td>
<td>31.4</td>
<td>8.6</td>
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<tr>
<td></td>
<td>LSD</td>
<td>NS</td>
<td>17.6</td>
<td>15.2</td>
<td>14.6</td>
<td>7.5</td>
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<td></td>
</tr>
</tbody>
</table>

^aAPBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

^bH = harvest.

^cAVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

^dLSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 29. Yield of fixed-N from four different cultivars of birdsfoot trefoil grown in mixed stands with orchardgrass and managed under a 3-cut system in 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Figure 30. Yield of fixed-N from four different cultivars of birdsfoot trefoil grown in mixed stands with orchardgrass and managed under a 3-cut system in 1991. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Values of %Ndfa usually peaked by midseason and then decreased slightly (Figure 31). Harvest differences were shown for all cultivars. Cultivars did not differ (P≤0.05) in %Ndfa in five of the six harvests. In harvest 4 (H4), APB-8701 had greater (P≤0.05) %Ndfa than Norcen. When averaged over the six harvests, APB-8701 had the greatest (P≤0.05) %Ndfa (95.4%) and Norcen had the least (93.5%) (Table 26).

Values of %Ndfa for the four cultivars in 1991 ranged from 95.5 to 97.9% over six harvests (Table 26). Values of %Ndfa for all cultivars were greatest in H1 and then tended to decrease over time (Figure 32). Harvest differences were shown for all cultivars. There were no differences (P≤0.05) observed among cultivars in any of the six harvests. When averaged over the six harvests, APB-8701 and Dawn had the greatest %Ndfa (96.6%), while Fergus and Norcen had the least (96.5%) (Table 26). These differences were not significant (P≤0.05), however.

Values of FNY ranged from 10.7 to 48.8 kg ha⁻¹ over six harvests in 1990 (Table 27). Fixed-N yields for all cultivars were always highest in H1 and tended to decrease over time (Figure 33). Harvest differences were shown for all four cultivars, although not necessarily among all harvests. No differences were shown among cultivars in four of the six harvests. In H3, both Fergus and Norcen yielded more (P≤0.05) fixed-N than APB-8701. In harvest 6 (H6), Fergus yielded more
Table 26. Percentage nitrogen derived from the atmosphere (%Ndfa) in herbage from four birdsfoot trefoil cultivars managed under a 6-cut system for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>Hb</th>
<th>Cultivara</th>
<th>APBT</th>
<th>DWN</th>
<th>FER</th>
<th>NOR</th>
<th>AVGc</th>
<th>LSDd</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>1</td>
<td>94.9</td>
<td>93.6</td>
<td>94.5</td>
<td>93.9</td>
<td>94.2</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
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aAPBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.
bH = harvest.
cAVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.
dLSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 31. Percentage N derived from the atmosphere in four different birdsfoot trefoil cultivars grown in mixed stands with orchardgrass and managed under a 6-cut system in 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Figure 32. Percentage N derived from the atmosphere in four different birdsfoot trefoil cultivars grown in mixed stands with orchardgrass and managed under a 6-cut system in 1991. LSD = least significant difference, P<0.05 (NS = no significant main effect)
Table 27. Yield of fixed-nitrogen in herbage from four cultivars of birdsfoot trefoil managed under a 6-cut system for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>H</th>
<th>Cultivar</th>
<th>APBT</th>
<th>DWN</th>
<th>FER</th>
<th>NOR</th>
<th>AVG</th>
<th>LSD</th>
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<td>10.7</td>
<td>14.3</td>
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<td>14.1</td>
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<td>AVG</td>
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<td>24.9</td>
<td>29.2</td>
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| 1991 | 1 | 22.3 | 32.3 | 40.8 | 35.9 | 32.9 | 16.5 |
|      | 2 | 11.8 | 12.7 | 14.0 | 19.1 | 14.4 | NS  |
|      | 3 | 7.1  | 5.7  | 29.2 | 6.6  | 12.1 | NS  |
|      | 4 | 4.4  | 6.1  | 6.0  | 5.6  | 5.5  | NS  |
|      | 5 | 8.6  | 13.1 | 13.3 | 13.7 | 12.2 | NS  |
|      | 6 | 12.3 | 24.5 | 14.5 | 21.2 | 18.1 | NS  |
| AVG  |   | 11.1 | 15.8 | 19.6 | 17.0 | 15.9 | 6.2 |
| LSD  |   | 7.8  | 12.3 | 26.0 | 10.8 | 7.6  |     |

^APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

^H = harvest.

^AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

^LSD = least significant difference; NS = no significant main effect, P>0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 33. Yield of fixed-N from four different cultivars of birdsfoot trefoil grown in mixed stands with orchardgrass and managed under a 6-cut system in 1990. LSD = least significant difference, $P \leq 0.05$ (NS = no significant main effect)
(P<0.05) fixed-N than APB-8701. When averaged over six harvests, APB-8701 yielded less (P<0.05) fixed-N than any of the other cultivars (Table 27).

Fixed-N yields in 1991 ranged from 4.4 to 40.8 kg ha\(^{-1}\) over six harvests (Table 27). Values of FNY for all cultivars were always highest in H1, declined to a low point at midseason, and then increased slightly at the end of the season (Figure 34). Harvest differences were shown for all cultivars. No differences were shown among cultivars in the last five harvests. In H1, APB-8701 yielded less (P<0.05) fixed-N than Fergus. When averaged over six harvests, Fergus yielded more (P<0.05) fixed-N than APB-8701 (Table 27).

**Total-season N\(_2\) fixation**  
Total-season %Ndfa for 1990 ranged from 97.6 to 98.0 and 93.5 to 95.4% for the 3-cut and 6-cut systems, respectively (Figure 35). The 3-cut system always showed a greater (P<0.05) %Ndfa than the 6-cut system for all four cultivars (Table 28). Mean %Ndfa was 3 to 4% greater for the 3-cut system for each of the cultivars. No differences (P<0.05) were shown, however, among cultivars within either harvest management.

Total-season %Ndfa for 1991 ranged from 97.4 to 98.6 and 96.5 to 96.6% for the 3-cut and 6-cut systems, respectively (Figure 36). The 3-cut system always showed a greater (P<0.05) %Ndfa than the 6-cut system for all four cultivars. Mean %Ndfa was 1 to 2% greater for the 3-cut system for each
Figure 34. Yield of fixed-N from four different cultivars of birdsfoot trefoil grown in mixed stands with orchardgrass and managed under a 6-cut system in 1991. LSD = least significant difference, P ≤ 0.05 (NS = no significant main effect)
Figure 35. Total-season percentage N derived from the atmosphere from four birdsfoot trefoil cultivars managed under 3- and 6-cut systems in 1990. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 28. Total-season percentage nitrogen derived from the atmosphere (%Ndfa) from four birdsfoot trefoil cultivars grown in association with orchardgrass and managed under two different harvest intensities for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>Mgt&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Cultivar&lt;sup&gt;a&lt;/sup&gt;</th>
<th>APBT</th>
<th>DWN</th>
<th>FER</th>
<th>NOR</th>
<th>LSD&lt;sup&gt;c&lt;/sup&gt;</th>
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<td></td>
<td>B</td>
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<td>94.1</td>
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<td>98.0</td>
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<td>97.7</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
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<td>96.6</td>
<td>96.5</td>
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<td>0.9</td>
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</table>

<sup>a</sup>APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

<sup>b</sup>Mgt = harvest management. A = 3-cut system; B = 6-cut system.

<sup>c</sup>LSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 36. Total-season percentage N derived from the atmosphere from four birdsfoot trefoil cultivars managed under 3- and 6-cut systems in 1991. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, $P \leq 0.05$ (NS = no significant main effect).
of the cultivars (Table 28). No differences (P ≤ 0.05) were shown among cultivars within the 6-cut system. For the 3-cut system, APB-8701 showed a greater (P ≤ 0.05) mean %Ndfa than Fergus.

Total-season FNYs for 1990 ranged from 143.0 to 204.1 and 149.4 to 186.5 kg ha⁻¹ for the 3-cut and 6-cut systems, respectively (Figure 37). Under the 3-cut system, both Dawn and Fergus yielded more (P ≤ 0.05) fixed-N than APB-8701 (Table 29). Under the 6-cut system, APB-8701 yielded less (P ≤ 0.05) fixed-N than any of the other cultivars. No differences (P ≤ 0.05) were shown between harvest management systems for any of the cultivars, however.

Total-season FNYs for 1991 ranged from 76.2 to 106.8 and 66.4 to 117.8 kg ha⁻¹ for the 3-cut and 6-cut systems, respectively (Figure 38). No significant differences (P ≤ 0.05) were shown among cultivars within either harvest management system (Table 29). Likewise, no differences (P ≤ 0.05) were shown between harvest management systems for any of the cultivars.

Percentage Ndfa for the 3-cut system tended to be related negatively to legume proportion in the BT mixtures for both years (Table 22). Regressions usually were not significant (P ≤ 0.05) for either year. Fixed-N yields for both years (3-cut system) tended to be related positively to legume
Figure 37. Total-season fixed-N yield from four birdsfoot trefoil cultivars managed under 3- and 6-cut systems in 1990. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 29. Total-season yield of fixed-nitrogen from four birdsfoot trefoil cultivars grown in association with orchardgrass and managed under two different harvest intensities for two years

<table>
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<tr>
<th>Year</th>
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<th>DWN</th>
<th>FER</th>
<th>NOR</th>
<th>LSD&lt;sup&gt;c&lt;/sup&gt;</th>
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<td>1990</td>
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<td>NS</td>
<td>NS</td>
<td>NS</td>
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</table>

| 1991 | A               |                      | 76.2  | 100.7 | 93.3  | 106.8 | NS          |
|      | B               |                      | 66.4  | 94.5  | 117.8 | 102.1 | NS          |
|      | LSD             | NS                   | NS    | NS   | NS   | NS   |              |

<sup>a</sup>APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

<sup>b</sup>Mgt = harvest management. A = 3-cut system; B = 6-cut system.

<sup>c</sup>LSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 38. Total-season fixed-N yield from four birdsfoot trefoil cultivars managed under 3- and 6-cut systems in 1991. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P<0.05 (NS = no significant main effect)
proportion in the mixtures (Table 22). Regressions usually were not significant (P≤0.05) for either year.

Percentage Ndfa for the 6-cut system tended to be related negatively to legume proportion in the BT mixtures for both years, also (Table 23). Regressions usually were not significant (P≤0.05) for either year. Fixed-N yields for both years (6-cut system) tended to be related positively to legume proportion in the mixtures (Table 23). Regressions usually were not significant (P≤0.05) for either year.

Transfer of fixed-N to associated orchardgrass

Three-cut system Values of %Ngdfa ranged from 37.7 to 51.2% over three harvests in 1990 (Table 30). Nitrogen transfer remained fairly constant over the growing season. No differences (P≤0.05) were shown among harvests for OG grown with any of the cultivars (Figure 39). Additionally, there were no differences (P≤0.05) in %Ngdfa shown among OG grown with any of the cultivars for any harvest. When averaged over three harvests, OG-APB derived the least amount of N from the atmosphere (41.5%) and OG-NOR derived the greatest amount (47.2%) (Table 30). These differences were not significant (P≤0.05), however.

Values of %Ngdfa in 1991 ranged from 28.8 to 64.1% over three harvests (Table 30). Harvest differences were shown for OG grown with all cultivars except Fergus. There were no
Table 30. Percentage nitrogen derived from the atmosphere in orchardgrass (\%Ngdfa) grown in association with four cultivars of birdsfoot trefoil managed under a 3-cut system for two years

<table>
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<th>Year</th>
<th>H&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Cultivar&lt;sup&gt;a&lt;/sup&gt;</th>
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<th>FER</th>
<th>NOR</th>
<th>AVG&lt;sup&gt;c&lt;/sup&gt;</th>
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</table>

<sup>a</sup>APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 39. Percentage harvested-N in orchardgrass derived from the atmosphere when grown with each respective birdsfoot trefoil cultivar and managed under a 3-cut system in 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect).
differences ($P \leq 0.05$) shown among cultivars in any harvest (Figure 40). When averaged over three harvests, OG-NOR derived the least amount of N from the atmosphere (40.3%) and OG-DWN derived the greatest amount (45.8%) (Table 30). These differences were not significant ($P \leq 0.05$), however.

Values of TNY ranged from 3.9 to 13.5 kg ha$^{-1}$ over three harvests in 1990 (Table 31). Transferred-N yields were lowest in H1 and increased with time (Figure 41). No differences ($P \leq 0.05$) were shown among harvests for any of the cultivars. Likewise, no differences ($P \leq 0.05$) were shown among any of the cultivars in any of the harvests. When averaged over three harvests, OG-APB had the greatest TNY (9.6 kg ha$^{-1}$) and OG-FER had the least (7.0 kg ha$^{-1}$), although differences in mean TNY were not significant ($P \leq 0.05$) (Table 31).

Values of TNY ranged from 6.4 to 14.0 kg ha$^{-1}$ over three harvests in 1991 (Table 31). Transferred-N yields usually were greatest in H2 (Figure 42). Harvest differences ($P \leq 0.05$) in TNY were shown for OG-DWN and OG-FER only. No differences ($P \leq 0.05$) were shown among OG grown with any of the cultivars in any of the harvests. When averaged over three harvests, OG-NOR had the least TNY (9.0 kg ha$^{-1}$) and OG-DWN had the greatest (10.5 kg ha$^{-1}$), although differences in mean TNY were not significant ($P \leq 0.05$) (Table 31).

**Six-cut system** Values of $\%$Ngdfa ranged from 0.0 to 82.2% over six harvests in 1990 (Table 32). Nitrogen transfer
Figure 40. Percentage harvested-N in orchardgrass derived from the atmosphere when grown with each respective birdsfoot trefoil cultivar and managed under a 3-cut system in 1991. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 31. Yield of transferred-nitrogen in herbage from orchardgrass grown in association with four cultivars of birdsfoot trefoil managed under a 3-cut system for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>H&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Cultivar&lt;sup&gt;a&lt;/sup&gt;</th>
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<th>DWN</th>
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<sup>a</sup>APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 41. Yield of transferred-N in orchardgrass grown with four different cultivars of birdsfoot trefoil and managed under a 3-cut system in 1990. LSD = least significant difference, \( P \leq 0.05 \) (NS = no significant main effect)
Figure 42. Yield of transferred-N in orchardgrass grown with four different cultivars of birdsfoot trefoil and managed under a 3-cut system in 1991. LSD = least significant difference, P<0.05 (NS = no significant main effect)
Table 32. Percentage nitrogen derived from the atmosphere in orchardgrass (%Ngdfa) grown in association with four cultivars of birdsfoot trefoil managed under a 6-cut system for two years

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<th>DWN</th>
<th>FER</th>
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</tbody>
</table>

\(^a\)APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

\(^b\)H = harvest.

\(^c\)AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

\(^d\)LSD = least significant difference; NS = no significant main effect, \(P \leq 0.05\). Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
tended to increase with time over the growing season (Figure 43). Harvest differences were shown for OG grown with all cultivars, although not necessarily among all harvests. There were no differences (P≤0.05) in %Ngdfa shown among cultivars, however. When averaged over six harvests, OG-APB derived the greatest amount of N from the atmosphere (59.6%) and OG-DWN derived the least amount (51.7%) (Table 32).

Values of %Ngdfa in 1991 ranged from 28.8 to 53.9% over six harvests (Table 32). Harvest differences were shown for OG-DWN and OG-FER only. There were no differences (P≤0.05) shown among cultivars in five of the six harvests (Figure 44). In H4, OG-DWN derived more (P≤0.05) N from fixation than OG-APB. When averaged over six harvests, OG-APB derived the least amount of N from fixation (34.1%), while OG-FER and OG-DWN derived the greatest amounts (42.6 and 42.4%, respectively) (Table 32).

Values of TNY ranged from 0.0 to 12.8 kg ha⁻¹ over six harvests in 1990 (Table 33). Transferred-N yield was lowest in H1 and tended to increase with time (Figure 45). Significant differences (P≤0.05) were shown among harvests for OG grown with all cultivars, although not necessarily among all harvests. No differences (P≤0.05) were shown among OG grown with any of the cultivars in any of the harvests. When averaged over six harvests, OG-APB had a greater TNY (6.8 kg ha⁻¹) than OG-FER (5.3 kg ha⁻¹) (Table 33).
Figure 43. Percentage harvested-N in orchardgrass derived from the atmosphere when grown with each respective birdsfoot trefoil cultivar and managed under a 6-cut system in 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Figure 44. Percentage harvested-N in orchardgrass derived from the atmosphere when grown with each respective birdsfoot trefoil cultivar and managed under a 6-cut system in 1991. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 33. Yield of transferred-nitrogen in herbage from orchardgrass grown in association with four cultivars of birdsfoot trefoil managed under a 6-cut system for two years

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<th>DWN</th>
<th>FER</th>
<th>NOR</th>
<th>AVG&lt;sup&gt;c&lt;/sup&gt;</th>
<th>LSD&lt;sup&gt;d&lt;/sup&gt;</th>
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</table>

<sup>a</sup>APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 45. Yield of transferred-N in orchardgrass grown with each respective cultivar of birdsfoot trefoil and managed under a 6-cut system in 1990. LSD = least significant difference, P<0.05 (NS = no significant main effect)
Values of TNY ranged from 2.1 to 7.4 kg ha\(^{-1}\) over six harvests in 1991 (Table 33). Transferred-N yields were highest in early season and tended to decrease somewhat with time (Figure 46). Significant differences (P≤0.05) were shown among harvests for OG grown with all cultivars except APB-8701, although not necessarily among all harvests. No differences (P≤0.05) were shown among OG grown with any of the cultivars in any of the harvests. When averaged over six harvests, OG-APB had a lower TNY (3.8 kg ha\(^{-1}\)) than OG-DWN and OG-FER (5.1 and 4.9 kg ha\(^{-1}\), respectively) (Table 33).

**Total-season N transfer**

Total-season %Ngdfa for 1990 ranged from 41.5 to 47.2 and 51.7 to 59.6% for the 3-cut and 6-cut systems, respectively (Figure 47). No significant differences (P≤0.05) in mean %Ngdfa were shown for OG grown with any of the cultivars within either harvest management system (Table 34). Mean %Ngdfa was always higher under the 6-cut system, however, differences between harvest management systems were nonsignificant (P≤0.05).

Total-season %Ngdfa for 1991 ranged from 40.3 to 45.8 and 34.1 to 42.6% for the 3-cut and 6-cut systems, respectively (Figure 48). No significant differences (P≤0.05) in mean %Ngdfa were shown for OG grown with any of the cultivars within either harvest management system (Table 34). Mean %Ngdfa was usually higher under the 3-cut system, however,
Figure 46. Yield of transferred-N in orchardgrass grown with each respective cultivar of birdsfoot trefoil and managed under a 6-cut system in 1991. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Figure 47. Total-season percentage harvested-N in orchardgrass derived from the atmosphere when grown with each respective birdsfoot trefoil cultivar and managed under 3- and 6-cut systems in 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 34. Total-season percentage nitrogen in grass derived from the atmosphere (%Ngdfa) from Orchardgrass grown in association with four birdsfoot trefoil cultivars and managed under two different harvest intensities for two years

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<th>FER</th>
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<td>NS</td>
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*APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

*Mgt = harvest management. A = 3-cut system; B = 6-cut system.

*LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 48. Total-season percentage harvested-N in orchardgrass derived from the atmosphere when grown with each respective birdsfoot trefoil cultivar and managed under 3- and 6-cut systems in 1991. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
differences between harvest management systems were
nonsignificant (P<0.05).

Total-season TNYs for 1990 ranged from 21.0 to 28.8 and
31.8 to 41.0 kg ha\(^{-1}\) for the 3-cut and 6-cut systems,
respectively (Figure 49). Orchardgrass grown in association
with APB-8701 yielded the greatest amount of transferred-N
under both harvest management systems, however, differences
among OG grown with any of the cultivars were nonsignificant
(P<0.05) (Table 35). Total-season TNYs were always greater
for the 6-cut system, however, only OG-DWN and OG-NOR showed
significant differences between harvest management systems.

Total-season TNYs for 1991 ranged from 26.9 to 31.5 and
22.5 to 30.7 kg ha\(^{-1}\) for the 3-cut and 6-cut systems,
respectively (Figure 50). Orchardgrass grown in association
with Dawn yielded the greatest amount of transferred-N under
both harvest management systems, however, differences among OG
grown with any of the cultivars were nonsignificant (P<0.05)
(Table 35). Total-season TNYs were always greater for the 3-
cut system, however, no significant differences (P<0.05) were
shown between harvest management systems.

For the 3-cut system in 1990, all mixtures except OG-NOR
showed a positive relationship between %Ngdfa and legume
proportion in the mixture, while in 1991, all mixtures showed
negative relationships between %Ngdfa and legume proportion
(Table 22). Regressions usually were not significant (P<0.05)
Figure 49. Total-season transferred-N yield in orchardgrass when grown with each respective birdsfoot trefoil cultivar and managed under 3- and 6-cut systems in 1990. LSD = least significant difference, P<0.05 (NS = no significant main effect)
Table 35. Total-season yield of transferred-nitrogen in orchardgrass grown in association with four birdsfoot trefoil cultivars and managed under two different harvest intensities for two years

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</table>

APBT = APB-8701; DWN = Dawn; FER = Fergus; NOR = Norcen.

Mgt = harvest management. A = 3-cut system; B = 6-cut system.

LSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 50. Total-season transferred-N yield in orchardgrass when grown with each respective birdsfoot trefoil cultivar and managed under 3- and 6-cut systems in 1991. LSD = least significant difference, $P \leq 0.05$ (NS = no significant main effect)
for either year. Transferred-N yields showed the same relationships in both years (Table 22). Likewise, regressions usually were not significant (P≤0.05) for any of the mixtures in either year.

For the 6-cut system in 1990, OG-FER and OG-NOR both showed positive relationships between %Ngdfa and legume proportion in the mixture, while in 1991, all mixtures showed negative relationships between %Ngdfa and legume proportion (Table 23). Regressions usually were not significant (P≤0.05) for either year. Transferred-N yields showed negative relationships for all mixtures in both years (Table 23). Similarly, regressions usually were not significant (P≤0.05) for any of the mixtures in either year.

Red clover dry matter yield

Three-cut system Dry matter yields for both years were always greatest in H1 and usually decreased over time (Figure 51). Yields for H1 in 1990 exceeded 4.5 Mg ha\(^{-1}\) while DM yields in H3 were 2.6 Mg ha\(^{-1}\) or less. Harvest differences were shown for all mixtures (Table 36). No significant differences were shown among mixtures for two of the three harvests. In H2, RII-OG, APR-OG, and ARL-OG each had a greater (P≤0.05) yield of herbage DM than MAM-OG. When averaged over three harvests, MAM-OG also yielded less (P≤0.05) herbage DM than the other mixtures (Table 36).
Figure 51. Herbage dry matter yields from four red clover/orchardgrass mixtures managed under a 3-cut system in 1990. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P<0.05 (NS = no significant main effect)
Table 36. Herbage dry matter yield of four red clover/orchardgrass mixtures managed under a 3-cut system for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>H^b</th>
<th>APRC</th>
<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>AVG^c</th>
<th>LSD^d</th>
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</thead>
<tbody>
<tr>
<td>1990</td>
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<td>4.8</td>
<td>4.9</td>
<td>4.8</td>
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</tr>
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<td>2</td>
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<td>2.8</td>
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<td>3.0</td>
<td>2.6</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.5</td>
<td>2.3</td>
<td>2.3</td>
<td>2.6</td>
<td>2.4</td>
<td>NS</td>
</tr>
<tr>
<td>AVG</td>
<td></td>
<td>3.5</td>
<td>3.2</td>
<td>3.0</td>
<td>3.5</td>
<td>3.3</td>
<td>0.3</td>
</tr>
<tr>
<td>LSD</td>
<td></td>
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<td>0.4</td>
<td>0.5</td>
<td>0.5</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>1</td>
<td>4.8</td>
<td>4.7</td>
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<td>NS</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.1</td>
<td>2.0</td>
<td>0.9</td>
<td>2.5</td>
<td>1.9</td>
<td>0.8</td>
</tr>
<tr>
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<td>1.7</td>
<td>1.5</td>
<td>0.6</td>
<td>1.5</td>
<td>1.3</td>
<td>0.2</td>
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<tr>
<td>AVG</td>
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<td>2.9</td>
<td>2.8</td>
<td>2.1</td>
<td>2.8</td>
<td>2.6</td>
<td>0.5</td>
</tr>
<tr>
<td>LSD</td>
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<td>1.3</td>
<td>0.9</td>
<td>0.7</td>
<td>0.7</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>

^aAPRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

^bH = harvest.

^cAVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

^dLSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Dry matter yields for H1 in 1991 exceeded 4.0 Mg ha\(^{-1}\) while DM yields in H3 were 1.7 Mg ha\(^{-1}\) or less (Figure 52). Harvest differences were shown for all mixtures (Table 36). In H1, no differences (P≤0.05) were shown among any of the mixtures. In H2 and H3, RII-OG, APR-OG, and ARL-OG all yielded more (P<0.05) herbage DM than MAM-OG. Likewise, when averaged over three harvests, MAM-OG yielded less (P≤0.05) herbage DM than the other mixtures (Table 36).

**Six-cut system** Dry matter yields for both years usually were greatest in H1 and tended to decrease over time (Figure 53). Herbage DM yields for 1990 ranged from 0.8 to 1.6 Mg ha\(^{-1}\). Harvest differences were shown for all mixtures, although not necessarily among all harvests (Table 37). In harvests where differences among mixtures were significant (P≤0.05), MAM-OG usually had the greatest (P≤0.05) yield of herbage DM and RII-OG usually had the least. When averaged over six harvests, RII-OG yielded the least (P≤0.05) amount of herbage DM of the four mixtures (Table 37).

Herbage DM yields for 1991 ranged from 0.3 to 2.7 Mg ha\(^{-1}\) (Figure 54). Harvest differences were shown for all mixtures, although not necessarily among all harvests (Table 37). Harvest differences among cultivars were shown for all harvests except H2. In harvests where differences among mixtures were significant (P≤0.05), MAM-OG had the lowest yield of herbage DM. Likewise, averaged over six harvests,
Figure 52. Herbage dry matter yields from four red clover/orchardgrass mixtures managed under a 3-cut system in 1991. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Figure 53. Herbage dry matter yields from four red clover/orchardgrass mixtures managed under a 6-cut system in 1990. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 37. Herbage dry matter yield of four red clover/orchardgrass mixtures managed under a 6-cut system for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>H&lt;sup&gt;b&lt;/sup&gt;</th>
<th>APRC</th>
<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>AVG&lt;sup&gt;c&lt;/sup&gt;</th>
<th>LSD&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
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<td>1990</td>
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<td>1.6</td>
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<td>1.5</td>
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</tr>
<tr>
<td></td>
<td>2</td>
<td>1.0</td>
<td>0.8</td>
<td>1.4</td>
<td>0.9</td>
<td>1.0</td>
<td>0.2</td>
</tr>
<tr>
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<td>1.0</td>
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<td>0.9</td>
<td>0.9</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>4</td>
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<td>1.0</td>
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<td>0.2</td>
</tr>
<tr>
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<td>1.2</td>
<td>1.1</td>
<td>NS</td>
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<tr>
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<td>6</td>
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<td>1.2</td>
<td>1.1</td>
<td>1.2</td>
<td>1.2</td>
<td>NS</td>
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<tr>
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<td>0.1</td>
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<td>2.7</td>
<td>2.2</td>
<td>0.6</td>
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<td>1.6</td>
<td>1.6</td>
<td>1.8</td>
<td>1.6</td>
<td>1.7</td>
<td>NS</td>
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</tr>
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<tr>
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<td>0.9</td>
<td>1.3</td>
<td>1.2</td>
<td>0.1</td>
</tr>
<tr>
<td>LSD</td>
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<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.4</td>
<td>0.2</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 54. Herbage dry matter yields from four red clover/orchardgrass mixtures managed under a 6-cut system in 1991. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
MAM-OG yielded less (P<0.05) herbage DM than the other mixtures (Table 37).

**Total-season DM yield**

Total-season DM yields in 1990 ranged from 8.9 to 10.5 and 6.6 to 7.1 Mg ha⁻¹ for the 3-cut and 6-cut systems, respectively (Figure 55). Under the 3-cut system, RII-OG and APR-OG yielded more (P<0.05) total DM than MAM-OG (Table 38). Under the 6-cut system, MAM-OG yielded the greatest amount of herbage DM, however, differences were not significant (P>0.05). For all mixtures, the 3-cut system yielded a significantly greater (P<0.05) amount of total herbage DM than the 6-cut system. Six-cut system yields were as much as 37% lower than DM yields from the 3-cut system.

Total-season DM yields in 1991 ranged from 6.2 to 8.6 and 5.7 to 7.7 Mg ha⁻¹ for the 3-cut and 6-cut systems, respectively (Figure 56). Under both harvest management systems, MAM-OG yielded less (P<0.05) total herbage DM than the other mixtures (Table 38). For all mixtures, the 3-cut system yielded a greater amount of total herbage DM than the 6-cut system, however, the 3-cut system yielded more (P<0.05) herbage DM than the 6-cut system for APR-OG only.

Legume proportions for the 3-cut system ranged from 61.3 to 92.8 and 15.0 to 69.6% for 1990 and 1991, respectively (Table 39). For the 3-cut system in 1990, APR-8701 maintained the highest (P<0.05) mean legume proportion in the mixture (83.0%) and Mammoth had the lowest (75.6%). For 1991 (3-cut
Figure 55. Total-season herbage dry matter yields from four red clover/orchardgrass mixtures managed under 3- and 6-cut systems in 1990. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 38. Total-season herbage dry matter yield of four red clover/orchardgrass mixtures managed under two different harvest intensities for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>Mgt</th>
<th>Cultivar</th>
<th>APRC</th>
<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>LSD°</th>
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</thead>
<tbody>
<tr>
<td>1990</td>
<td>A</td>
<td>APRC</td>
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<td>8.9</td>
<td>10.5</td>
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</tr>
<tr>
<td></td>
<td>B</td>
<td>ARL</td>
<td>7.0</td>
<td>7.0</td>
<td>7.1</td>
<td>6.6</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>LSD</td>
<td>LSD</td>
<td>1.2</td>
<td>1.1</td>
<td>0.8</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>A</td>
<td>MAM</td>
<td>8.6</td>
<td>8.3</td>
<td>6.2</td>
<td>8.2</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>RII</td>
<td>7.5</td>
<td>7.4</td>
<td>5.7</td>
<td>7.7</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>LSD</td>
<td>LSD</td>
<td>0.8</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

°LSD = least significant difference; NS = no significant main effect, \( P \leq 0.05 \). Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.

®APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

^Mgt = harvest management. A = 3-cut system; B = 6-cut system.
Figure 56. Total-season herbage dry matter yields from four red clover/orchardgrass mixtures managed under 3- and 6-cut systems in 1991. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 39. Legume proportion of four red clover/orchardgrass mixtures managed under a 3-cut system for two different years

<table>
<thead>
<tr>
<th>Year</th>
<th>H&lt;sup&gt;b&lt;/sup&gt;</th>
<th>APRC</th>
<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>AVG&lt;sup&gt;c&lt;/sup&gt;</th>
<th>LSD&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>92.3</td>
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<td>73.2</td>
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<td>69.2</td>
<td>69.1</td>
<td>12.0</td>
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<td>80.0</td>
<td>78.6</td>
<td>6.4</td>
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<tr>
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<td>5.6</td>
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</tr>
<tr>
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<td>68.8</td>
<td>63.2</td>
<td>13.4</td>
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<td>64.1</td>
<td>15.0</td>
<td>66.2</td>
<td>53.6</td>
<td>11.4</td>
</tr>
<tr>
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<td>32.8</td>
<td>63.1</td>
<td>56.7</td>
<td>10.0</td>
</tr>
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<td>NS</td>
<td>19.1</td>
<td>NS</td>
<td>8.7</td>
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</tbody>
</table>

<sup>a</sup>APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P ≤ 0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
system), Arlington maintained the greatest ($P \leq 0.05$) mean legume proportion in the mixture (66.8%), while Mammoth had the least (32.8%). Mean RC DM yields for the 3-cut system in 1990 showed positive relationships between DM yield and legume proportion in the mixtures only for APR-8701 and Redland II (Table 40). Mean RC DM yields for the 3-cut system in 1991 showed positive relationships with legume proportion in the mixtures only for Arlington and Redland II (Table 40). Regressions were not significant ($P < 0.05$) for any of the mixtures in either year.

Legume proportions for the 6-cut system ranged from 42.2 to 93.2 and 15.1 to 71.3% for 1990 and 1991, respectively (Table 41). For the 6-cut system in 1990, Mammoth maintained the highest ($P \leq 0.05$) mean legume proportion in the mixture (67.5%) and Arlington had the lowest (63.4%). For 1991 (6-cut system), APR-8701 maintained the greatest ($P \leq 0.05$) mean legume proportion in the mixture (57.7%), while Mammoth had the least (30.7%). No differences ($P \leq 0.05$) in legume proportion in the mixtures were shown between the two management systems for any of the cultivars except APR-8701 for 1990 (Table 42). Significant differences ($P \leq 0.05$) in legume proportion in the mixture were shown in five of the six harvests for 1991. Where differences were significant, Mammoth showed a lower legume proportion in the mixture than any of the other cultivars. Mean RC DM yields for the 6-cut system tended to
Table 40. Regression equations of DM yield (DM), N₂ fixation (%Ndfa), fixed-N yield (FNY), N transfer (%Ngdfa), and transferred-N yield (TNY) on percentage legume in four RC/OG mixtures managed under a 3-cut system for two years.

<table>
<thead>
<tr>
<th>CV²</th>
<th>VAR²</th>
<th>Equation</th>
<th>R</th>
<th>SE²</th>
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<th>R</th>
<th>SE²</th>
<th>1991</th>
<th>R</th>
<th>SE²</th>
</tr>
</thead>
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<td>NS</td>
<td>8.9 - 0.01X</td>
<td>0.05</td>
<td>NS</td>
<td>8.9 - 0.01X</td>
<td>0.05</td>
<td>NS</td>
</tr>
<tr>
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<td>DM</td>
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<td>NS</td>
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<td>NS</td>
<td>2.1 + 0.09X</td>
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<td>NS</td>
</tr>
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<td>NS</td>
<td>6.8 - 0.02X</td>
<td>0.18</td>
<td>NS</td>
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<td>0.05</td>
<td>NS</td>
<td>94.3 - 0.02X</td>
<td>0.05</td>
<td>NS</td>
</tr>
<tr>
<td>MAM</td>
<td>%Ndfa</td>
<td>100.1 - 0.10X</td>
<td>0.47</td>
<td>NS</td>
<td>95.3 + 0.01X</td>
<td>0.36</td>
<td>NS</td>
<td>95.3 + 0.01X</td>
<td>0.36</td>
<td>NS</td>
</tr>
<tr>
<td>RII</td>
<td>%Ndfa</td>
<td>104.4 - 0.13X</td>
<td>0.48</td>
<td>NS</td>
<td>95.6 - 0.02X</td>
<td>0.10</td>
<td>NS</td>
<td>95.6 - 0.02X</td>
<td>0.10</td>
<td>NS</td>
</tr>
<tr>
<td>APRC</td>
<td>FNY</td>
<td>223.9 + 0.42X</td>
<td>0.08</td>
<td>NS</td>
<td>-68.3 + 3.19X</td>
<td>0.75</td>
<td>NS</td>
<td>-68.3 + 3.19X</td>
<td>0.75</td>
<td>NS</td>
</tr>
<tr>
<td>ARL</td>
<td>FNY</td>
<td>-187.8 + 5.13X</td>
<td>0.58</td>
<td>NS</td>
<td>-39.3 + 3.06X</td>
<td>0.65</td>
<td>NS</td>
<td>-39.3 + 3.06X</td>
<td>0.65</td>
<td>NS</td>
</tr>
<tr>
<td>MAM</td>
<td>FNY</td>
<td>-643.4 + 12.10X</td>
<td>0.82</td>
<td>NS</td>
<td>26.8 + 1.54X</td>
<td>0.99</td>
<td>0.2</td>
<td>26.8 + 1.54X</td>
<td>0.99</td>
<td>0.2</td>
</tr>
<tr>
<td>RII</td>
<td>FNY</td>
<td>416.8 - 2.07X</td>
<td>0.82</td>
<td>NS</td>
<td>-174.2 + 5.13X</td>
<td>0.99</td>
<td>6.1</td>
<td>-174.2 + 5.13X</td>
<td>0.99</td>
<td>6.1</td>
</tr>
<tr>
<td>APRC</td>
<td>%Ngdfa</td>
<td>153.6 - 1.57X</td>
<td>0.59</td>
<td>NS</td>
<td>92.0 - 0.77X</td>
<td>0.67</td>
<td>NS</td>
<td>92.0 - 0.77X</td>
<td>0.67</td>
<td>NS</td>
</tr>
<tr>
<td>ARL</td>
<td>%Ngdfa</td>
<td>207.4 - 2.39X</td>
<td>0.66</td>
<td>NS</td>
<td>10.7 + 0.40X</td>
<td>0.32</td>
<td>NS</td>
<td>10.7 + 0.40X</td>
<td>0.32</td>
<td>NS</td>
</tr>
<tr>
<td>MAM</td>
<td>%Ngdfa</td>
<td>132.4 - 1.44X</td>
<td>0.95</td>
<td>4.2</td>
<td>43.3 + 0.02X</td>
<td>0.04</td>
<td>NS</td>
<td>43.3 + 0.02X</td>
<td>0.04</td>
<td>NS</td>
</tr>
<tr>
<td>RII</td>
<td>%Ngdfa</td>
<td>123.2 - 1.31X</td>
<td>0.84</td>
<td>NS</td>
<td>94.1 - 0.84X</td>
<td>0.52</td>
<td>NS</td>
<td>94.1 - 0.84X</td>
<td>0.52</td>
<td>NS</td>
</tr>
<tr>
<td>APRC</td>
<td>TNY</td>
<td>81.0 - 0.86X</td>
<td>0.74</td>
<td>NS</td>
<td>79.0 - 0.80X</td>
<td>0.84</td>
<td>NS</td>
<td>79.0 - 0.80X</td>
<td>0.84</td>
<td>NS</td>
</tr>
<tr>
<td>ARL</td>
<td>TNY</td>
<td>155.4 - 1.86X</td>
<td>0.72</td>
<td>NS</td>
<td>55.9 - 0.43X</td>
<td>0.26</td>
<td>NS</td>
<td>55.9 - 0.43X</td>
<td>0.26</td>
<td>NS</td>
</tr>
<tr>
<td>MAM</td>
<td>TNY</td>
<td>82.1 - 0.94X</td>
<td>0.98</td>
<td>1.5</td>
<td>31.4 - 0.05X</td>
<td>0.06</td>
<td>NS</td>
<td>31.4 - 0.05X</td>
<td>0.06</td>
<td>NS</td>
</tr>
<tr>
<td>RII</td>
<td>TNY</td>
<td>99.7 - 1.12X</td>
<td>0.94</td>
<td>3.1</td>
<td>78.4 - 0.76X</td>
<td>0.54</td>
<td>NS</td>
<td>78.4 - 0.76X</td>
<td>0.54</td>
<td>NS</td>
</tr>
</tbody>
</table>

- CV = cultivar. APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.
- VAR = response variable; DM in Mg ha⁻¹, FNY and TNY in kg ha⁻¹.
- SE = square root of the mean square error; NS = no significant effect (P<0.05).
Table 41. Legume proportion of four red clover/orchardgrass mixtures managed under a 6-cut system for two different years

<table>
<thead>
<tr>
<th>Year</th>
<th>H&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Cultivar&lt;sup&gt;a&lt;/sup&gt;</th>
<th>APRC</th>
<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>AVG&lt;sup&gt;c&lt;/sup&gt;</th>
<th>LSD&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>1</td>
<td>87.2</td>
<td>90.2</td>
<td>90.0</td>
<td>93.2</td>
<td>90.1</td>
<td>NS</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>75.4</td>
<td>71.2</td>
<td>83.3</td>
<td>78.0</td>
<td>77.0</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>72.2</td>
<td>66.4</td>
<td>72.7</td>
<td>72.9</td>
<td>71.1</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>64.9</td>
<td>59.4</td>
<td>61.5</td>
<td>56.6</td>
<td>60.6</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>49.3</td>
<td>50.3</td>
<td>55.2</td>
<td>45.6</td>
<td>50.1</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>46.3</td>
<td>43.1</td>
<td>42.2</td>
<td>48.7</td>
<td>45.1</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>1</td>
<td>71.3</td>
<td>67.2</td>
<td>50.9</td>
<td>64.2</td>
<td>63.4</td>
<td>13.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>48.7</td>
<td>45.4</td>
<td>39.6</td>
<td>36.9</td>
<td>42.6</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>54.7</td>
<td>48.2</td>
<td>24.6</td>
<td>56.5</td>
<td>46.0</td>
<td>11.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>70.6</td>
<td>73.9</td>
<td>26.3</td>
<td>60.6</td>
<td>57.9</td>
<td>16.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>61.5</td>
<td>65.0</td>
<td>27.7</td>
<td>55.6</td>
<td>52.4</td>
<td>15.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>39.6</td>
<td>43.0</td>
<td>15.1</td>
<td>42.4</td>
<td>35.0</td>
<td>16.8</td>
<td></td>
</tr>
<tr>
<td>AVG</td>
<td>57.7</td>
<td>57.1</td>
<td>30.7</td>
<td>52.7</td>
<td>49.6</td>
<td>6.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSD</td>
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<td>14.2</td>
<td>13.6</td>
<td>15.0</td>
<td>7.7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Table 42. Total-season legume proportion of four red clover:orchardgrass mixtures managed under two different harvest intensities for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>Mgt&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Cultivar&lt;sup&gt;a&lt;/sup&gt;</th>
<th>APRC</th>
<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>LSD&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>A</td>
<td>APRC</td>
<td>83.0</td>
<td>75.9</td>
<td>75.6</td>
<td>80.0</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>ARL</td>
<td>65.9</td>
<td>63.4</td>
<td>66.7</td>
<td>66.3</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>LSD</td>
<td></td>
<td>15.7</td>
<td>NS</td>
<td>NS</td>
<td>8.8</td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>A</td>
<td>MAM</td>
<td>64.1</td>
<td>66.8</td>
<td>32.8</td>
<td>63.1</td>
<td>11.4</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>RII</td>
<td>57.7</td>
<td>57.1</td>
<td>32.9</td>
<td>50.3</td>
<td>8.7</td>
</tr>
<tr>
<td></td>
<td>LSD</td>
<td></td>
<td>NS</td>
<td>9.5</td>
<td>NS</td>
<td>10.4</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

<sup>b</sup>Mgt = harvest management. A = 3-cut system; B = 6-cut system.

<sup>c</sup>LSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
be related positively to legume proportion in the mixtures for both years (Table 43). Regressions usually were not significant (P ≤ 0.05) for either year, however.

**N₂ fixation by red clover**

**Three-cut system**  Values of %Ndfa for the four cultivars ranged from 90.1 to 93.8% over three harvests in 1990 (Table 44). Values of %Ndfa tended to be fairly consistent throughout the growing season (Figure 57). No harvest differences (P ≤ 0.05) were shown for any of the mixtures. Cultivars did not differ (P ≤ 0.05) in %Ndfa in any harvest. When averaged over the three harvests, Redland II had the greatest %Ndfa (93.6%) and APR-8701 had the least (91.0%), however, these differences were not significant (P ≤ 0.05) (Table 44).

Values of %Ndfa for the four cultivars in 1991 ranged from 92.8 to 96.4% over three harvests (Table 44). Values of %Ndfa tended to be fairly consistent throughout the growing season (Figure 58). No harvest differences (P ≤ 0.05) were shown for any of the mixtures. In H1, Mammoth had greater (P ≤ 0.05) %Ndfa than both APR-8701 and Arlington. No differences in %Ndfa were shown among mixtures in H2 and H3. When averaged over the three harvests, Mammoth had the greatest (P ≤ 0.05) %Ndfa (95.7%), while APR-8701 and Arlington had the least (93.8 and 92.9%, respectively) (Table 44).
Table 43. Regression equations of DM yield (DM), N$_2$ fixation (%Ndfa), fixed-N yield (FNY), N transfer (%Ngdfa), and transferred-N yield (TNY) on percentage legume in four RC/OG mixtures managed under a 6-cut system for two years.

<table>
<thead>
<tr>
<th>CV$^a$</th>
<th>VAR$^b$</th>
<th>1990</th>
<th></th>
<th>1991</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Equation</td>
<td>R</td>
<td>SE$^c$</td>
<td>Equation</td>
<td>R</td>
</tr>
<tr>
<td>APRC</td>
<td>DM</td>
<td>6.7 + 0.01X</td>
<td>0.43</td>
<td>NS</td>
<td>6.1 + 0.02X</td>
</tr>
<tr>
<td>ARL</td>
<td>DM</td>
<td>5.5 + 0.02X</td>
<td>0.42</td>
<td>NS</td>
<td>9.0 - 0.03X</td>
</tr>
<tr>
<td>MAM</td>
<td>DM</td>
<td>8.3 - 0.02X</td>
<td>0.41</td>
<td>NS</td>
<td>2.8 + 0.09X</td>
</tr>
<tr>
<td>RII</td>
<td>DM</td>
<td>5.3 + 0.02X</td>
<td>0.15</td>
<td>NS</td>
<td>-6.5 + 0.28X</td>
</tr>
<tr>
<td>APRC</td>
<td>%Ndfa</td>
<td>92.1 + 0.07X</td>
<td>0.72</td>
<td>NS</td>
<td>93.0 + 0.03X</td>
</tr>
<tr>
<td>ARL</td>
<td>%Ndfa</td>
<td>99.0 - 0.03X</td>
<td>0.81</td>
<td>NS</td>
<td>95.6 - 0.02X</td>
</tr>
<tr>
<td>MAM</td>
<td>%Ndfa</td>
<td>105.2 - 0.14X</td>
<td>0.84</td>
<td>NS</td>
<td>88.7 + 0.14X</td>
</tr>
<tr>
<td>RII</td>
<td>%Ndfa</td>
<td>88.3 + 0.12X</td>
<td>0.75</td>
<td>NS</td>
<td>60.7 + 0.60X</td>
</tr>
<tr>
<td>APRC</td>
<td>FNY</td>
<td>-58.2 + 3.52X</td>
<td>0.99</td>
<td>4.2</td>
<td>-57.9 + 3.49X</td>
</tr>
<tr>
<td>ARL</td>
<td>FNY</td>
<td>16.1 + 2.72X</td>
<td>0.83</td>
<td>NS</td>
<td>-23.4 + 2.77X</td>
</tr>
<tr>
<td>MAM</td>
<td>FNY</td>
<td>-294.9 + 7.33X</td>
<td>0.95</td>
<td>19.7</td>
<td>-229.8 + 8.97X</td>
</tr>
<tr>
<td>RII</td>
<td>FNY</td>
<td>-160.6 + 5.20X</td>
<td>0.81</td>
<td>NS</td>
<td>-30.9 + 2.96X</td>
</tr>
<tr>
<td>APRC</td>
<td>%Ngdfa</td>
<td>71.7 - 0.51X</td>
<td>0.41</td>
<td>NS</td>
<td>66.1 - 0.38X</td>
</tr>
<tr>
<td>ARL</td>
<td>%Ngdfa</td>
<td>78.1 - 0.72X</td>
<td>0.59</td>
<td>NS</td>
<td>119.3 - 1.34X</td>
</tr>
<tr>
<td>MAM</td>
<td>%Ngdfa</td>
<td>113.1 - 1.16X</td>
<td>0.57</td>
<td>NS</td>
<td>97.3 - 1.71X</td>
</tr>
<tr>
<td>RII</td>
<td>%Ngdfa</td>
<td>-109.8 + 2.40X</td>
<td>0.59</td>
<td>NS</td>
<td>201.3 - 3.14X</td>
</tr>
<tr>
<td>APRC</td>
<td>TNY</td>
<td>67.7 - 0.74X</td>
<td>0.65</td>
<td>NS</td>
<td>73.2 - 0.75X</td>
</tr>
<tr>
<td>ARL</td>
<td>TNY</td>
<td>66.3 - 0.75X</td>
<td>0.66</td>
<td>NS</td>
<td>114.7 - 1.46X</td>
</tr>
<tr>
<td>MAM</td>
<td>TNY</td>
<td>83.6 - 0.94X</td>
<td>0.49</td>
<td>NS</td>
<td>28.6 - 0.05X</td>
</tr>
<tr>
<td>RII</td>
<td>TNY</td>
<td>-62.3 + 1.36X</td>
<td>0.54</td>
<td>NS</td>
<td>147.8 - 2.30X</td>
</tr>
</tbody>
</table>

$^aCV$ = cultivar. APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

$^bVAR$ = response variable; DM in Mg ha$^{-1}$, FNY and TNY in kg ha$^{-1}$.

$^cSE$ = square root of the mean square error; NS = no significant effect (P$\leq$0.05).
Table 44. Percentage nitrogen derived from the atmosphere (%Nd\text{fa}) in herbage from four red clover cultivars managed under a 3-cut system for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>H\textsuperscript{b}</th>
<th>Cultivar\textsuperscript{a}</th>
<th>APRC</th>
<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>AVG\textsuperscript{c}</th>
<th>LSD\textsuperscript{d}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>1</td>
<td>91.4</td>
<td>92.2</td>
<td>93.5</td>
<td>93.5</td>
<td>92.7</td>
<td>92.9</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>2</td>
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<td>93.6</td>
<td>90.5</td>
<td>93.5</td>
<td>92.3</td>
<td>94.0</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>90.1</td>
<td>93.8</td>
<td>92.8</td>
<td>93.8</td>
<td>92.6</td>
<td>94.5</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>AVG</td>
<td>91.0</td>
<td>93.2</td>
<td>92.3</td>
<td>93.6</td>
<td>92.5</td>
<td>94.5</td>
<td>NS</td>
</tr>
<tr>
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<td>LSD</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
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<td>1991</td>
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<td>92.9</td>
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<td>92.8</td>
<td>95.5</td>
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<td>94.0</td>
<td>94.5</td>
<td>NS</td>
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<td>3</td>
<td>94.5</td>
<td>92.9</td>
<td>96.4</td>
<td>94.3</td>
<td>94.5</td>
<td>94.3</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>AVG</td>
<td>93.8</td>
<td>92.9</td>
<td>95.7</td>
<td>94.3</td>
<td>94.1</td>
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<td>NS</td>
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</tr>
</tbody>
</table>

\textsuperscript{a}APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

\textsuperscript{b}H = harvest.

\textsuperscript{c}AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

\textsuperscript{d}LSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 57. Percentage N derived from the atmosphere in four different red clover cultivars grown in mixed stands with orchardgrass and managed under a 3-cut system in 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Figure 58. Percentage N derived from the atmosphere in four different red clover cultivars grown in mixed stands with orchardgrass and managed under a 3-cut system in 1991. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Values of FNY ranged from 37.5 to 180.3 kg ha$^{-1}$ over three harvests in 1990 (Table 45). Fixed-N yields for all cultivars were always highest in H1 and decreased over time (Figure 59). Harvest differences were shown for all four cultivars. No differences were shown among cultivars in any harvest. When averaged over three harvests, Mammoth yielded the greatest amount of fixed-N, however, this yield was not significantly different ($P \leq 0.05$) from the yields of the other cultivars (Table 45).

Fixed-N yields in 1991 ranged from 5.0 to 80.3 kg ha$^{-1}$ over three harvests (Table 45). Values of FNY for all cultivars usually were highest in H1 and decreased with time (Figure 60). Harvest differences ($P \leq 0.05$) were shown for all cultivars except APR-8701. No differences were shown among cultivars in H1. In H2 and H3, Mammoth yielded less ($P \leq 0.05$) fixed-N than any of the other cultivars. Likewise, when averaged over three harvests, Mammoth yielded less ($P \leq 0.05$) fixed-N than any of the other cultivars (Table 45).

**Six-cut system** Values of %Ndfa for the four cultivars ranged from 92.4 to 99.6% over six harvests in 1990 (Table 46). Values of %Ndfa tended to increase over time (Figure 61). Harvest differences were shown for all cultivars, although not necessarily among all harvests. Cultivars did not differ ($P \leq 0.05$) in %Ndfa in five of the six harvests. In H6, Mammoth had the lowest ($P \leq 0.05$) %Ndfa. When averaged over
Table 45. Yield of fixed-nitrogen in herbage from four cultivars of red clover managed under a 3-cut system for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>H&lt;sup&gt;b&lt;/sup&gt;</th>
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<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>AVG&lt;sup&gt;c&lt;/sup&gt;</th>
<th>LSD&lt;sup&gt;d&lt;/sup&gt;</th>
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<sup>a</sup>APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 59. Yield of fixed-N from four different cultivars of red clover grown in mixed stands with orchardgrass and managed under a 3-cut system in 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Figure 60. Yield of fixed-N from four different cultivars of red clover grown in mixed stands with orchardgrass and managed under a 3-cut system in 1991. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
### Table 46. Percentage nitrogen derived from the atmosphere (%Ndfa) in herbage from four red clover cultivars managed under a 6-cut system for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>H&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Cultivar&lt;sup&gt;a&lt;/sup&gt;</th>
<th>APRC</th>
<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>AVG&lt;sup&gt;c&lt;/sup&gt;</th>
<th>LSD&lt;sup&gt;d&lt;/sup&gt;</th>
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<td>97.1</td>
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<td>98.0</td>
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<td>96.4</td>
<td>96.5</td>
<td>0.9</td>
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</tr>
<tr>
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<td>2.1</td>
<td>1.2</td>
<td></td>
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</tbody>
</table>

| 1991 | 1             | 92.9                 | 95.1 | 94.3 | 94.0 | 1.7           |               |
|      | 2             | 94.0                 | 87.4 | 94.4 | 92.5 | NS            |               |
|      | 3             | 93.9                 | 93.6 | 94.1 | 94.0 | NS            |               |
|      | 4             | 95.7                 | 95.0 | 95.5 | 95.4 | NS            |               |
|      | 5             | 95.7                 | 95.2 | 94.2 | 95.2 | NS            |               |
|      | 6             | 95.0                 | 94.7 | 93.8 | 94.6 | NS            |               |
| AVG  |               | 94.5                 | 93.3 | 94.6 | 94.3 | NS            |               |
| LSD  |               | 1.7                  | 1.4  | NS   | NS   | 2.4           |               |

<sup>a</sup>APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 61. Percentage N derived from the atmosphere in four different red clover cultivars grown in mixed stands with orchardgrass and managed under a 6-cut system in 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
the six harvests, both APR-8701 and Arlington had greater (P≤0.05) \%Ndfa than Mammoth (Table 46).

Values of \%Ndfa for the four cultivars in 1991 ranged from 87.4 to 95.7\% over six harvests (Table 46). Values of \%Ndfa for all cultivars tended to increase slightly over time (Figure 62). Harvest differences (P≤0.05) were shown for APR-8701 and Arlington only. In H1, APR-8701 had a lower (P≤0.05) \%Ndfa than Mammoth. There were no differences (P≤0.05) observed among cultivars in the last five harvests. When averaged over the six harvests, Arlington had the greatest \%Ndfa (94.7\%), while Mammoth had the least (93.3\%) (Table 46). These differences were not significant (P≤0.05), however.

Values of FNY ranged from 15.3 to 88.0 kg ha\(^{-1}\) over six harvests in 1990 (Table 47). Fixed-N yields for all cultivars were always highest in H1 and tended to decrease over time (Figure 63). Harvest differences were shown for all four cultivars, although not necessarily among all harvests. No differences were shown among cultivars in five of the six harvests. In H2, Mammoth yielded more (P≤0.05) fixed-N than any of the other cultivars. When averaged over six harvests, Mammoth yielded the greatest amount of fixed-N (32.9 kg ha\(^{-1}\)) and APR-8701 yielded the least amount (29.0 kg ha\(^{-1}\)) (Table 47). These differences were not significant (P≤0.05), however.

Fixed-N yields in 1991 ranged from 3.2 to 60.5 kg ha\(^{-1}\)
Figure 62. Percentage N derived from the atmosphere in four different red clover cultivars grown in mixed stands with orchardgrass and managed under a 6-cut system in 1991. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 47. Yield of fixed-nitrogen in herbage from four cultivars of red clover managed under a 6-cut system for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>H&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Cultivar&lt;sup&gt;a&lt;/sup&gt;</th>
<th>APRC</th>
<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>AVG&lt;sup&gt;c&lt;/sup&gt;</th>
<th>LSD&lt;sup&gt;d&lt;/sup&gt;</th>
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<sup>a</sup>APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 63. Yield of fixed-N from four different cultivars of red clover grown in mixed stands with orchardgrass and managed under a 6-cut system in 1990. LSD = least significant difference, \( P \leq 0.05 \) (NS = no significant main effect)
over six harvests (Table 47). Values of FNY for all cultivars were always highest in H1 and decreased over time (Figure 64). Harvest differences were shown for all cultivars. Differences (P ≤ 0.05) were shown among cultivars in five of the six harvests. In harvests where differences in FNY were significant, Mammoth always showed less %Ndfa than the other cultivars. When averaged over three harvests, APR-8701, Arlington, and Redland II yielded more (P ≤ 0.05) fixed-N than Mammoth (Table 47).

Total-season N₂ fixation Total-season %Ndfa for 1990 ranged from 91.0 to 93.6 and 95.8 to 97.0% for the 3-cut and 6-cut systems, respectively (Figure 65). The 6-cut system always showed a greater (P ≤ 0.05) %Ndfa than the 3-cut system for all four cultivars (Table 48). Mean %Ndfa was approximately 4% greater for the 6-cut system for each of the cultivars. No differences (P ≤ 0.05) were shown, however, among cultivars within either harvest management.

Total-season %Ndfa for 1991 ranged from 92.9 to 95.7 and 90.6 to 94.7% for the 3-cut and 6-cut systems, respectively (Figure 66). No differences (P ≤ 0.05) were shown between harvest management system for any of the cultivars (Table 48). No differences (P ≤ 0.05) were shown among cultivars within the 6-cut system. For the 3-cut system, Mammoth showed a greater (P ≤ 0.05) mean %Ndfa than Arlington.

Total-season FNYs for 1990 ranged from 201.5 to 271.0 and
Figure 64. Yield of fixed-N from four different cultivars of red clover grown in mixed stands with orchardgrass and managed under a 6-cut system in 1991. LSD = least significant difference, P<0.05 (NS = no significant main effect)
Figure 65. Total-season percentage N derived from the atmosphere from four red clover cultivars managed under 3- and 6-cut systems in 1990. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 48. Total-season percentage nitrogen derived from the atmosphere (%Ndfa) from four red clover cultivars grown in association with orchardgrass and managed under two different harvest intensities for two years

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<th>Year</th>
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<th>Cultivar&lt;sup&gt;a&lt;/sup&gt;</th>
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<th>MAM</th>
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</table>

<sup>a</sup>APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

<sup>b</sup>Mgt = harvest management. A = 3-cut system; B = 6-cut system.

<sup>c</sup>LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 66. Total-season percentage N derived from the atmosphere from four red clover cultivars managed under 3- and 6-cut systems in 1991. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, \( P<0.05 \) (NS = no significant main effect)
173.8 to 194.4 kg ha\(^{-1}\) for the 3-cut and 6-cut systems, respectively (Figure 67). The 3-cut system yielded a greater (P≤0.05) total amount of fixed-N over the 6-cut system for both APR-8701 and Redland II (Table 49). No differences (P≤0.05) in total FNY were shown between harvest management systems for either Arlington or Mammoth.

Total-season FNYs for 1991 ranged from 77.2 to 164.9 and 65.7 to 143.8 kg ha\(^{-1}\) for the 3-cut and 6-cut systems, respectively (Figure 68). Under both harvest management systems, Mammoth yielded less (P≤0.05) total fixed-N than any of the other cultivars (Table 49). No significant differences (P≤0.05) were shown between harvest management systems for any of the cultivars.

Percentage Ndfa for the 3-cut system tended to be related negatively to legume proportion in the RC mixtures for both years (Table 40). Regressions usually were not significant (P≤0.05) for either year. Fixed-N yields for both years (3-cut system) tended to be related positively to legume proportion in the mixtures (Table 40). Similarly, regressions usually were not significant (P≤0.05) for either year.

Percentage Ndfa for the 6-cut system tended to be related negatively to legume proportion in the RC mixtures for both years, also (Table 43). Regressions usually were not significant (P≤0.05) for either year. Fixed-N yields for both years (6-cut system) were related positively to legume
Figure 67. Total-season fixed-N yield from four red clover cultivars managed under 3- and 6-cut systems in 1990. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 49. Total-season yield of fixed-nitrogen from four red clover cultivars grown in association with orchardgrass and managed under two different harvest intensities for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>Mgt&lt;sup&gt;b&lt;/sup&gt;</th>
<th>APRC</th>
<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>LSD&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>kg ha&lt;sup&gt;-1&lt;/sup&gt;</td>
<td></td>
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</tr>
<tr>
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<td>251.0</td>
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</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>1991</td>
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</tr>
<tr>
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<td>65.7</td>
<td>118.0</td>
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<td>LSD</td>
<td>NS</td>
<td>NS</td>
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<td></td>
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</table>

<sup>a</sup>APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

<sup>b</sup>Mgt = harvest management. A = 3-cut system; B = 6-cut system.

<sup>c</sup>LSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 68. Total-season fixed-N yield from four red clover cultivars managed under 3- and 6-cut systems in 1991. Shaded portion of column represents legume fraction; unshaded portion of column represents grass fraction. LSD = least significant difference, $P \leq 0.05$ (NS = no significant main effect)
proportion for all mixtures (Table 43). Regressions usually were not significant (P≤0.05) for either year.

Transfer of fixed-N to associated orchardgrass

Three-cut system Values of %Ngdfa ranged from 6.8 to 34.1% over three harvests in 1990 (Table 50). Nitrogen transfer was always lowest for H2 and highest for H3 (Figure 69). No harvest differences (P≤0.05) were shown for OG grown with any of the cultivars except OG-RII. There were no differences (P≤0.05) in %Ngdfa shown among OG grown with any of the four cultivars. When averaged over three harvests, OG-RII derived the least amount of N from the atmosphere (18.3%) and OG-ARL derived the greatest amount (26.3%) (Table 50).

Values of %Ngdfa in 1991 ranged from 24.4 to 57.5% over three harvests (Table 50). Harvest differences were shown for OG grown with all cultivars except Redland II. There were no differences (P≤0.05) shown among cultivars in H1 (Figure 70). In H2, OG-APR had a greater (P≤0.05) %Ngdfa than OG-ARL. In H3, OG-MAM had a greater (P≤0.05) %Ngdfa than OG-RII. When averaged over three harvests, OG-ARL derived the least amount of N from the atmosphere (37.6%) and OG-MAM derived the greatest amount (44.0%) (Table 50). These differences were not significant (P≤0.05), however.

Values of TNY ranged from 1.4 to 5.7 kg ha\(^{-1}\) over three harvests in 1990 (Table 51). Transferred-N yield usually was
Table 50. Percentage nitrogen derived from the atmosphere in orchardgrass (%Ngdfa) grown in association with four cultivars of red clover managed under a 3-cut system for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>H</th>
<th>APRC</th>
<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>AVG</th>
<th>LSD</th>
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<td>NS</td>
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<td>44.8</td>
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<td>LSD</td>
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<td>12.3</td>
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</tr>
</tbody>
</table>

\(^a\)APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

\(^b\)H = harvest.

\(^c\)AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

\(^d\)LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 69. Percentage harvested-N in orchardgrass derived from the atmosphere when grown with each respective red clover cultivar and managed under a 3-cut system in 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Figure 70. Percentage harvested-N in orchardgrass derived from the atmosphere when grown with each respective red clover cultivar and managed under a 3-cut system in 1991. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 51. Yield of transferred-nitrogen in herbage from orchardgrass grown in association with four cultivars of red clover managed under a 3-cut system for two years.

<table>
<thead>
<tr>
<th>Year</th>
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<th>APRC</th>
<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>AVG</th>
<th>LSD</th>
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<td>2.9</td>
<td>4.4</td>
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<td>1.6</td>
<td>3.1</td>
<td>NS</td>
</tr>
<tr>
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<td>3</td>
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<td>5.1</td>
<td>5.7</td>
<td>5.6</td>
<td>5.2</td>
<td>NS</td>
</tr>
<tr>
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<td>3.4</td>
<td>4.7</td>
<td>3.6</td>
<td>3.5</td>
<td>3.9</td>
<td>NS</td>
</tr>
<tr>
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<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>2.0</td>
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<td>10.6</td>
<td>14.0</td>
<td>11.2</td>
<td>9.8</td>
<td>11.4</td>
<td>NS</td>
</tr>
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<td>12.0</td>
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<td>10.9</td>
<td>14.3</td>
<td>11.4</td>
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<td>6.0</td>
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<tr>
<td>AVG</td>
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</tr>
<tr>
<td>LSD</td>
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<td>6.4</td>
<td>NS</td>
<td>7.5</td>
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</tr>
</tbody>
</table>

\(^{a}\)APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

\(^{b}\)H = harvest.

\(^{c}\)AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

\(^{d}\)LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
lowest in H1 and increased with time (Figure 71). No
differences (P≤0.05) were shown among harvests for any of the
cultivars. Likewise, no differences (P≤0.05) were shown among
any of the cultivars in any of the harvests. When averaged
over three harvests, OG-ARL had the greatest TNY (4.7 kg ha⁻¹)
and OG-APR had the least (3.4 kg ha⁻¹), although differences
in mean TNY were not significant (P≤0.05) (Table 51).

Values of TNY ranged from 4.6 to 14.3 kg ha⁻¹ over three
harvests in 1991 (Table 51). Transferred-N yield always was
lowest in H3 (Figure 72). Harvest differences (P≤0.05) in TNY
were shown only for OG-APR, OG-ARL, and OG-RII. No
differences (P≤0.05) were shown among OG grown with any of the
cultivars in H1 and H3. In H2, OG-RII showed a greater
(P≤0.05) yield of transferred-N than OG-ARL. When averaged
over three harvests, OG-ARL had the least TNY (9.1 kg ha⁻¹),
while OG-MAM and OG-RII had the greatest (10.0 kg ha⁻¹),
although differences in mean TNY were not significant (P≤0.05)
(Table 51).

Six-cut system Values of %Ngdfa ranged from 15.7 to
62.4% over six harvests in 1990 (Table 52). Nitrogen transfer
tended to increase to midseason and then gradually decreased
over the remainder of the growing season (Figure 73). Harvest
differences were shown for OG grown with all cultivars,
although not necessarily among all harvests. There were no
differences (P≤0.05) in %Ngdfa shown among cultivars in four
Figure 71. Yield of transferred-N in orchardgrass grown with four different cultivars of red clover and managed under a 3-cut system in 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Figure 72. Yield of transferred-N in orchardgrass grown with four different cultivars of red clover and managed under a 3-cut system in 1991. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 52. Percentage nitrogen derived from the atmosphere in orchardgrass (%Ngdfa) grown in association with four cultivars of red clover managed under a 6-cut system for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>H&lt;sup&gt;b&lt;/sup&gt;</th>
<th><strong>Cultivar</strong>&lt;sup&gt;a&lt;/sup&gt;</th>
<th>APRC</th>
<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>AVG&lt;sup&gt;c&lt;/sup&gt;</th>
<th>LSD&lt;sup&gt;d&lt;/sup&gt;</th>
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<tbody>
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<td>19.1</td>
<td>18.2</td>
<td>35.6</td>
<td>28.6</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>54.1</td>
<td>44.8</td>
<td>44.5</td>
<td>62.4</td>
<td>51.4</td>
<td>12.0</td>
<td></td>
</tr>
<tr>
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<td>3</td>
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<td>53.6</td>
<td>51.5</td>
<td>50.9</td>
<td>50.5</td>
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</tr>
<tr>
<td></td>
<td>4</td>
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<td>41.0</td>
<td>45.2</td>
<td>57.0</td>
<td>46.4</td>
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<td>15.7</td>
<td>27.5</td>
<td>27.9</td>
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</table>

<sup>a</sup>APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

<sup>b</sup>H = harvest.

<sup>c</sup>AVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

<sup>d</sup>LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 73. Percentage harvested-N in orchardgrass derived from the atmosphere when grown with each respective red clover cultivar and managed under a 6-cut system in 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
of the six harvests. In H2, OG-RII had a greater (P≤0.05) %Ngdfa than either OG-ARL or OG-MAM. In H6, OG-RII had a greater (P≤0.05) %Ngdfa than OG grown with any of the other cultivars. When averaged over six harvests, OG-RII derived a greater (P≤0.05) amount of N from the atmosphere (47.8%) than either OG-MAM (37.5%) or OG-ARL (32.7%) (Table 52).

Values of %Ngdfa in 1991 ranged from 29.5 to 53.7% over six harvests (Table 52). Harvest differences were shown for OG-APR, OG-ARL, and OG-MAM only. There were no differences (P≤0.05) shown among cultivars in any of the six harvests (Figure 74). When averaged over six harvests, OG-MAM derived the least amount of N from fixation (40.5%), while OG-RII derived the greatest amount (45.1%) (Table 52).

Values of TNY ranged from 1.3 to 8.2 kg ha⁻¹ over six harvests in 1990 (Table 53). Transferred-N yield tended to increase with time up to H4 and then decreased slightly (Figure 75). Significant differences (P≤0.05) were shown among harvests for OG-MAM and OG-RII only, although not necessarily among all harvests. No differences (P≤0.05) were shown among OG grown with any of the cultivars in any of the harvests. When averaged over six harvests, OG-RII had the greatest TNY (4.4 kg ha⁻¹) and OG-ARL had the least (3.1 kg ha⁻¹) (Table 53). These differences were not significant (P≤0.05), however.

Values of TNY ranged from 2.3 to 9.4 kg ha⁻¹ over six
Figure 74. Percentage harvested-N in orchardgrass derived from the atmosphere when grown with each respective red clover cultivar and managed under a 6-cut system in 1991. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 53. Yield of transferred-nitrogen in herbage from orchardgrass grown in association with four cultivars of red clover managed under a 6-cut system for two years

<table>
<thead>
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<th>Year</th>
<th>( H^b )</th>
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<th>MAM</th>
<th>RII</th>
<th>AVG^c</th>
<th>LSD^d</th>
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</tr>
<tr>
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<td>1.5</td>
<td>1.3</td>
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</table>

^aAPRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

^bH = harvest.

^cAVG = average. Column averages are cultivar means within a year; row averages are harvest means within a year.

^dLSD = least significant difference; NS = no significant main effect, P ≤ 0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 75. Yield of transferred-N in orchardgrass grown with each respective cultivar of red clover and managed under a 6-cut system in 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
harvests in 1991 (Table 53). Transferred-N yield was highest in the first half of the season and then tended to decrease somewhat with time (Figure 76). Significant differences (P≤0.05) were shown among harvests for OG grown with all cultivars, although not necessarily among all harvests. No differences (P≤0.05) were shown among OG grown with any of the cultivars in five of the six harvests. In H3, OG-ARL had a greater (P≤0.05) TNY than OG-MAM. When averaged over six harvests, OG-MAM had the least TNY (4.5 kg ha⁻¹) and OG-RII had the greatest (5.5 kg ha⁻¹) (Table 53). These differences were not significant (P≤0.05), however.

Total-season N transfer Total-season %Ngdfa for 1990 ranged from 18.3 to 26.3 and 32.7 to 49.6% for the 3-cut and 6-cut systems, respectively (Figure 77). No significant differences (P≤0.05) in mean %Ngdfa were shown for OG grown with any of the cultivars within either harvest management system (Table 54). Mean %Ngdfa was always higher under the 6-cut system, however, differences between harvest management systems were significant (P≤0.05) for OG-RII only. Nitrogen transfer from RII was 171% greater under the 6-cut system when compared to the 3-cut system.

Total-season %Ngdfa for 1991 ranged from 37.6 to 44.0 and 40.9 to 44.5% for the 3-cut and 6-cut systems, respectively (Figure 78). No significant differences (P≤0.05) in mean %Ngdfa were shown for OG grown with any of the cultivars
Figure 76. Yield of transferred-N in orchardgrass grown with each respective cultivar of red clover and managed under a 6-cut system in 1991. LSD = least significant difference, P<0.05 (NS = no significant main effect)
Figure 77. Total-season percentage harvested-N in orchardgrass derived from the atmosphere when grown with each respective red clover cultivar and managed under 3- and 6-cut systems in 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 54. Total-season percentage nitrogen in grass derived from the atmosphere (%Ngdfa) from orchardgrass grown in association with four red clover cultivars and managed under two different harvest intensities for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>Mgt&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Cultivar&lt;sup&gt;a&lt;/sup&gt;</th>
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<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>LSD&lt;sup&gt;c&lt;/sup&gt;</th>
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</tr>
</tbody>
</table>

<sup>a</sup>APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

<sup>b</sup>Mgt = harvest management. A = 3-cut system; B = 6-cut system.

<sup>c</sup>LSD = least significant difference; NS = no significant main effect, P<0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 78. Total-season percentage harvested-N in orchardgrass derived from the atmosphere when grown with each respective red clover cultivar and managed under 3- and 6-cut systems in 1991. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
within either harvest management system (Table 54). Mean %Ngdfa was usually higher under the 6-cut system, however, differences between harvest management systems were nonsignificant (P≤0.05).

Total-season TNYs for 1990 ranged from 10.1 to 14.0 and 18.9 to 28.0 kg ha\(^{-1}\) for the 3-cut and 6-cut systems, respectively (Figure 79). Differences among OG grown with any of the cultivars were nonsignificant (P≤0.05) under either management system (Table 55). Total-season TNYs were always greater for the 6-cut system, however, only OG-RII showed a significant difference (P≤0.05) between harvest management systems. Nitrogen transfer from RII was 167% greater under the 6-cut system when compared to the 3-cut system.

Total-season TNYs for 1991 ranged from 27.2 to 30.1 and 27.0 to 32.2 kg ha\(^{-1}\) for the 3-cut and 6-cut systems, respectively (Figure 80). Orchardgrass grown in association with Redland II yielded the greatest amount of transferred-N under both harvest management systems, however, differences among OG grown with any of the cultivars were nonsignificant (P≤0.05) (Table 55). Total-season TNYs usually were greater for the 6-cut system, however, no significant differences (P≤0.05) were shown between harvest management systems.

For the 3-cut system in 1990, all mixtures showed a negative relationship between %Ngdfa and legume proportion in the mixture, while in 1991, only APR-8701 and Redland II
Figure 79. Total-season transferred-N yield in orchardgrass when grown with each respective red clover cultivar and managed under 3- and 6-cut systems in 1990. LSD = least significant difference, P≤0.05 (NS = no significant main effect)
Table 55. Total-season yield of transferred-nitrogen in orchardgrass grown in association with four red clover cultivars and managed under two different harvest intensities for two years

<table>
<thead>
<tr>
<th>Year</th>
<th>Mgt</th>
<th>Cultivar</th>
<th>APRC</th>
<th>ARL</th>
<th>MAM</th>
<th>RII</th>
<th>LSD°</th>
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<td></td>
<td>B</td>
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<td>18.9</td>
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<tr>
<td></td>
<td>LSD</td>
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<tr>
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®APRC = APR-8701; ARL = Arlington; MAM = Mammoth; RII = Redland II.

*Mgt = harvest management. A = 3-cut system; B = 6-cut system.

°LSD = least significant difference; NS = no significant main effect, P≤0.05. Row LSDs refer to cultivar differences within a harvest; column LSDs refer to harvest differences within a cultivar.
Figure 80. Total-season transferred-N yield in orchardgrass when grown with each respective red clover cultivar and managed under 3- and 6-cut systems in 1991. LSD = least significant difference, *P*≤0.05 (NS = no significant main effect)
showed negative relationships between %Ngdfa and legume proportion (Table 40). Regressions usually were not significant (P≤0.05) for either year. Transferred-N yields showed negative relationships for all mixtures in both years (Table 40). Similarly, regressions usually were not significant (P≤0.05) for any of the mixtures in either year.

For the 6-cut system in 1990, all mixtures except OG-RII showed negative relationships between %Ngdfa and legume proportion in the mixture, while in 1991, all mixtures showed negative relationships between %Ngdfa and legume proportion (Table 43). Regressions usually were not significant (P≤0.05) for either year. Likewise, TNYs were negatively related for all mixtures in both years except for OG-RII in 1990 (Table 43). Regressions usually were not significant (P≤0.05) for any of the mixtures in either year.
DISCUSSION

Experiment One

Dry matter yield

The droughty conditions that persisted during the seeding year (1988) resulted in very little legume or grass growth. Improved moisture conditions in early 1989, however, stimulated growth of all species. Dry conditions resumed in the latter half of the 1989 growing season and DM yields of H2 and H3 were reduced considerably.

Above average precipitation from April through June 1990 resulted in greatly improved DM yields for both BT and RC mixtures. Actual legume DM yields did not change appreciably from 1989 to 1990. Dry matter yield for each mixture in 1990 was affected more by grass yield. Total herbage DM yield, as well as the yield of the grass component in each mixture, primarily were enhanced by association with a legume. This relationship has been reported previously (Hamilton et al., 1969; Whitehead, 1970; Dubbs, 1971; Wilman, 1977).

Mean BT DM yields were related positively to legume proportion in the mixtures for both years. Cultivar or harvest differences in legume proportion usually were not significant (P≤0.05). Therefore, legume persistence in the mixtures was very similar for all four cultivars in both
years. In both 1989 and 1990, legume proportions of all BT mixtures were highest in H2. This most likely reflects the dry growing conditions which reduced grass growth more than legume growth. The deeper rooting depth of BT resulted in a larger area of the soil profile from which water could be extracted, thus temporarily reducing the effects of the dry conditions.

Mean RC DM yields also were related positively to legume proportion in the mixtures for both years. Cultivar or harvest differences in legume proportion usually were not significant (P≤0.05) in 1989. Therefore, legume persistence in the mixtures was very similar for all four cultivars in second-year growth. In 1989, legume proportions of the RC mixtures were highest for all cultivars in H1. The RC root system is typically altered in the second year of growth by loss or degeneration of the taproot. This forces the RC plant to rely upon a secondary root system and, consequently, would result in reduced drought tolerance. In 1990, legume proportions of the RC mixtures consistently decreased over time. Mean legume proportion decreased by 46% which, as explained previously, most likely is the result of the altered root system of the RC plant. The reduction in root mass by the loss of the tap root can result in decreased plant growth and, ultimately, death of the RC plant. Legume proportion of Mammoth usually was significantly (P≤0.05) lower in 1990 than
the other cultivars. This demonstrates a lower productivity over time for Mammoth.

**N₂ fixation**

Values of %Ndfa for both BT and RC usually were greater than 90% and frequently greater than 95%. These relatively high values most likely are the result of low soil N concentrations. The finer and more dense root systems of the associated OG would be more competitive for available soil N and, thus, soil N would become depleted. Dinitrogen fixation processes in the legume are stimulated under conditions of low soil N. Additionally, swards were seeded in 1988, whereas sampling was initiated in 1989 (second-year stands). Consequently, legume rooting and fixing systems would be more developed and operative in an established stand, compared to seeding-year stands.

In 1989, values of %Ndfa for all BT and RC cultivars usually were highest in H1 and decreased over time. This observation contradicts findings by Heichel et al. (1985), which showed N₂ fixation by BT and RC peaking by midseason. The decreasing trends observed in this study may have reflected the unusually dry conditions in the latter half of the growing season. These dry conditions affected cultivars of both species similarly, however. Results observed in 1990 also were contradictory to those reported by Heichel et al.
Values of %Ndfa for both BT and RC were highest in H1 and lowest in H2. This also reflects the relatively dry conditions that were experienced in midseason of 1990. All cultivars were affected similarly as usually no differences in N₂ fixation were shown among cultivars for any harvest.

Percentage Ndfa tended to be related positively to legume proportion in the BT mixtures for 1989. The opposite was true for mixtures in 1990. Mean legume proportion for BT declined 32% from 1989 to 1990, however, mean %Ndfa increased by only 1.8%. Birdsfoot trefoil mixtures in 1989 usually had larger (P≤0.05) legume proportions, while %Ndfa between the two years differed very little or not at all. In 1989, positive relationships between legume proportion and %Ndfa were shown for all cultivars except Fergus. This would indicate that the dry conditions of 1989 not only affected legume growth of APB-8701, Dawn, and Norcen, but likewise reduced N₂ fixation by these cultivars. Similarly, dry matter yields of Fergus were reduced by the dry conditions, but N₂ fixation was not affected as severely. Percentage Ndfa always was related negatively to legume proportion in the mixtures for all BT cultivars in 1990.

Percentage Ndfa tended to be related positively to legume proportion in the RC mixtures for both years. Mean legume proportion for RC declined 46% from 1989 to 1990, while mean %Ndfa increased by only 1.5%. Although legume proportion of
the RC mixtures was always greater in 1989, differences in %Ndfa between years for each cultivar usually did not exist. In 1989, only Arlington showed a negative relationship between legume proportion in the mixture and %Ndfa. As was mentioned previously with Fergus BT, this suggests that the dry conditions of 1989 not only affected legume growth of APR-8701, Mammoth, and Redland II, but likewise reduced N₂ fixation. The dry conditions did reduce DM yields of Arlington, but N₂ fixation by Arlington was not affected as severely. Both Arlington and Redland II showed negative relationships between %Ndfa and legume proportion in the mixtures in 1990.

The relationship of decreased legume proportion in the stand and the resultant increase in %Ndfa was reported by Mallarino et al. (1990) and Heichel and Henjum (1991). It has been shown, also, that %Ndfa is greater in legume-grass mixtures than in pure stands of legume (Edmeades and Goh, 1978; West and Wedin, 1985; Brophy et al., 1987). The reason given is that as legume proportion and legume DM yield increases, the legume competes more favorably with the grass for available soil N. Therefore, as grass proportion increases (legume proportion decreases), soil-N would be depleted more by the grass and N₂ fixation by the legume would be stimulated. As explained previously, the dry conditions would tend to affect grass growth more than legume growth,
resulting in greater legume:grass ratios. Thus, the larger legume proportions in the mixtures would result in reduced $N_2$ fixation. This may explain, partially, the frequent positive relationships between legume proportion in the mixtures and %Ndfa for cultivars of both species, especially in 1989.

Fixed-N yield for both BT and RC decreased over time in each year and is described most accurately by the comparable decrease in legume DM yield over time. Legume FNYs for both BT and RC usually were related positively to legume proportion in the stand. This agrees with findings by Mallarino et al. (1990). They reported that legume-dominant swards were required to maximize FNYs for both BT and RC mixtures. This relationship shows that as the amount of legume herbage increases, the amount of $N_2$ fixed per unit area of land increases, also. Thus, any negative effects resulting from decreased %Ndfa would tend to be offset. Consequently, total-season yields of fixed-N for both BT and RC were slightly less for 1990 than 1989. Although DM yields of 1990 were greater, legume proportions in the mixtures were appreciably less and resulted in lower yields of fixed-N.

Transfer of fixed-N to associated orchardgrass

The reduced amounts of N transfer in 1989, compared to 1990, reflect the relatively dry conditions of the latter half of the 1989 growing season and the lower OG DM yields (usually
less than 1.5 Mg ha\(^{-1}\)). Mean \%Ngdfa values were greater in 1990 than in 1989 by 258\% for BT and 50\% for RC. These increases most likely resulted from the improved moisture conditions in 1990. In 1990, \%Ngdfa averaged slightly more than 40\% for BT and nearly 70\% for RC. These findings are in accordance with findings by Boller and Nösberger (1987) and Brophy et al. (1987). Decomposition of plant materials (above-ground parts as well as sloughed roots and nodules) and the mineralization and liberation of N from these plant materials would be enhanced under more favorable moisture conditions. A consequence of the isotope dilution technique is that this technique does not discriminate between N\(_2\) fixed in different years. Therefore, some of the N that was mineralized and released for uptake by the grass could actually have come from fixation that occurred in 1989. This would tend to over-estimate N transfer in 1990.

Nitrogen transfer to associated OG (%Ngdfa) was quite variable among harvests in 1989 for both BT and RC. Percentage Ngdfa was usually highest in H1 and lowest in H2. There was much less variability in 1990, however, with %Ngdfa tending to decrease over time. This coincides with reports by Heichel and Henjum (1991) that showed a decline in N transfer with time being associated with a reduced legume proportion in the sward, a loss of root-plus-crown DM accumulation, and reduced growth of legume and grass components of the swards.
This is contradictory, however, to findings by Brophy et al. (1987) and Mallarino et al. (1990). Brophy et al. (1987) noted several factors that could contribute to a seasonal increase in N transfer, including increased depletion of available soil N, greater \( \text{N}_2 \) fixation capability by the legumes, and greater root intermingling.

Values of TNY in 1989 were quite variable, most likely a result of the dry growing conditions. Transferred-N yields were not as variable within harvests of 1990 as in 1989. Even though grass:legume ratios increased with time, TNYs tended to decrease as OG DM yields decreased with time. When sampling in the seeding year was included, Brophy et al. (1987) and Mallarino et al. (1990) showed TNY increased over time, a result that is contradictory to findings in this study.

Dinitrogen fixation is typically low shortly after planting and transfer mechanisms such as nodule and root turnover are not fully operative. In this study, however, an established stand existed. Therefore, in 1990 (third growing season), root and \( \text{N}_2 \) fixing systems would be more fully developed and operative. Any changes in N transfer would be more dependent on environmental conditions and legume proportion in the stand.

Percentage Ngdfa values for BT mixtures usually were related negatively to legume proportion in the mixtures for 1989, while the opposite was true for TNYs. Percentage Ngdfa
and TNYs for all BT mixtures in 1990 usually were related negatively to legume proportion in the mixtures. Mean %Ngdfa values and TNYs for RC mixtures were related positively to legume proportion in the mixtures for both years. The usually negative relationships between %Ngdfa and legume proportion in the mixtures contradict the aforementioned premises relating increased legume proportion in the mixture to decreased N₂ fixation and increased FNY, which was reported by Mallarino et al. (1990). As legume proportion increases, actual N₂ fixation would decrease but total N fixed per unit area (FNY) would increase (more legume herbage per unit area). Thus, larger FNYs (greater legume proportions) would result in greater amounts of fixed-N available for transfer to the associated grass (greater %Ngdfa). This relationship tended to hold true for RC cultivars in both years, but was contradictory for BT cultivars. Likewise, as legume proportion decreases, total transferred-N per unit area (TNY) would increase (greater grass herbage per unit area). This relationship was not evident for most RC mixtures in 1989, but tended to hold true for most RC mixtures in 1990. A possible explanation for the differing relationships between RC and BT might stem from altered root structures of RC as was mentioned previously. The loss of the tap root by RC would reduce greatly the amount of RC root mass and would consequently decrease its ability to compete with grass roots for liberated
N. Birdsfoot trefoil root systems, on the other hand, would remain virtually intact and continue to compete favorably with the grass for liberated N. In low soil-N environments, however, the legume root may actually out-compete the grass root for released N, as the legume root would be in closer proximity to the released N. This occurrence is difficult to prove, however.

Experiment Two

Dry matter yield

Above average precipitation in early Spring 1990 and again in 1991 resulted in high DM yields for both BT and RC mixtures. The grass component in each mixture tended to increase with time for both BT and RC mixtures. As explained previously in Exp. 1, total herbage DM yield, as well as the yield of the grass component in each mixture, primarily were enhanced by association with a legume. This relationship has been reported previously (Hamilton et al., 1969; Whitehead, 1970; Dubbs, 1971; Wilman, 1977).

The frequency of defoliation resulted in large differences in total-season DM yields for both BT and RC. Total-season herbage DM yields from the 3-cut system were always greater than the 6-cut system for all cultivars of BT and RC. Dry matter yields for BT mixtures were as much as 33%
greater for the 3-cut system. Dry matter yields for RC mixtures were as much as 37% greater for the 3-cut system in 1990, however, DM yields did not differ between the two management systems for 1991. Defoliating more frequently would affect plant growth by limiting stem growth and resulting in more leaf growth. This was more evident for the legumes than the grass. The 6-cut system severely limited total legume production, however, grass growth seemingly was enhanced by the more frequent defoliations. This was not tested statistically, however. Reasons for this increased response of the grass to a more intense management regime most likely are related to nitrogen release from the legumes and will be covered later in this section.

Mean BT DM yields usually were related positively to legume proportion in the mixtures for both years. Legume persistence was reduced, somewhat, by the different harvest managements. Mean BT legume proportion declined approximately 19% from 1990 to 1991 for the 3-cut system. For the 6-cut system, mean BT legume proportion declined by more than 35% from 1990 to 1991. This further shows the effect of the severe harvest management on legume persistence and the consequential stimulation of the grass component of the mixtures.

Mean RC DM yields showed a mixed relationship to legume proportion in the mixtures for the 3-cut system in both years.
For the 6-cut system, however, RC DM yields tended to be related positively to legume proportion in the mixtures for both years. Legume persistence was more positive for RC than BT. Mean RC legume proportion declined approximately 28% from 1990 to 1991 for the 3-cut system. For the 6-cut system, mean RC legume proportion declined by only 25% from 1990 to 1991. Therefore, RC legume persistence in the mixtures was very similar for the two experimental years. The only exception is Mammoth. Mean legume proportion of Mammoth declined by 57% from 1990 to 1991 for the 3-cut system, and by nearly 80% from 1990 to 1991 for the 6-cut system. The alteration of the Mammoth root system, as explained previously, most likely caused this reduction in plant growth. Additionally, Mammoth ceases to form elongated stems after the initial defoliation and regrowth is primarily leafy.

\textbf{N}_2 \textbf{fixation}

Values of %Ndfa for both BT and RC usually were greater than 90% and frequently greater than 95% for both harvest management systems. These relatively high values most likely are the result of low soil N concentrations. The finer and more dense root systems of the associated OG would be more competitive for available soil N and, thus, soil N would become depleted. Dinitrogen fixation processes in the legume are stimulated under conditions of low soil N. This was
explained previously in Exp. 1. Percentage Ndfa tended to be related negatively to legume proportion in the BT mixtures for both harvest management systems in both years.

For the 3-cut system in 1990, values of %Ndfa for all BT cultivars were highest in H3 and lowest in H2. This observation contradicts findings by Heichel et al. (1985), which showed N₂ fixation by BT and RC peaking by midseason. In 1991, %Ndfa for all BT cultivars except Fergus was highest in H2. This observation tends to follow what was shown by Heichel et al. (1985). Mean %Ndfa increased only slightly (<1%) from 1990 to 1991. For the 6-cut system in 1990, %Ndfa for BT cultivars tended to peak by midseason and then decline slightly. In 1991, however, %Ndfa for all BT cultivars tended to decrease over the growing season. Mean %Ndfa for the 6-cut system increased by a small percentage (2.3%) from 1990 to 1991. This increase in mean %Ndfa with time also was shown by Mallarino et al. (1990).

For the 3-cut system in both years, values of %Ndfa for all RC cultivars did not differ among harvests. Mean %Ndfa for RC cultivars increased slightly (1.7%) from 1990 to 1991. For the 6-cut system in both years, %Ndfa for RC cultivars tended to increase over the growing season. Mean %Ndfa for the 6-cut system decreased by a small percentage (2.3%) from 1990 to 1991. Percentage Ndfa tended to be related negatively to legume proportion in the RC mixtures for both years of the
3-cut system, while \%Ndfa tended to be related positively to legume proportion in the RC mixtures for both years of the 6-cut system. This would explain the slight decrease in \%Ndfa from 1990 to 1991, as previously described in Exp. 1.

Total-season \%Ndfa for BT cultivars was always less for the 6-cut system. Total-season \%Ndfa for RC cultivars was always greater for the 6-cut system in 1990, however, management systems did not differ in \%Ndfa for 1991. Cralle and Heichel (1981) explained that the removal of photosynthetic tissue at harvest and the competition between vegetative regrowth and nodules for reserve carbohydrates and current photosynthate may affect adversely the capacity of nodules to sustain \( N_2 \) fixation. The frequent defoliations also would affect the root/nodule systems of the legumes. Nodules would be shed in response to the defoliation and extra energy would be required to form new nodules. This reduction in nodule numbers and total root mass, in response to defoliation, would tend to reduce overall \( N_2 \) fixation. The increased \( N_2 \) fixation for the 6-cut system of RC over the 3-cut system may be explained by the reduction in legume proportion in the 6-cut system. Mean RC legume proportion of the 6-cut system was reduced by 13-17\% when compared to the 3-cut system. This reduction in legume proportion would have a stimulatory affect on \( N_2 \) fixation, as explained in Exp. 1.

Fixed-N yield for both BT and RC reflected changes in
legume DM yield for both harvest managements and both years. Legume FNYs for both BT and RC usually were related positively to legume proportion in the stand for both harvest managements. This agrees with findings by Mallarino et al. (1990) and was explained previously. Total-season BT and RC FNYs tended to be higher for the 3-cut system, however, FNYs usually did not differ between harvest managements for either year.

Transfer of fixed-N to associated orchardgrass

Mean %Ngdfa values for BT were greater in 1990 than in 1991 by 5 and 29% for 3-cut and 6-cut systems, respectively. Similar results were reported by Heichel and Henjum (1991), as explained in Exp. 1. Mean %Ngdfa values for RC were greater in 1991 than in 1990 by 45 and 11% for 3-cut and 6-cut systems, respectively. This is contradictory to the findings by Heichel and Henjum (1991), however, it is in accordance with findings by Brophy et al. (1987) and Mallarino et al. (1990). Brophy et al. (1987) noted several factors that could contribute to a seasonal increase in N transfer, including increased depletion of available soil N, greater N$_2$ fixation capability by the legumes, and greater root intermingling.

Total-season N transfer from BT was 19% greater for the 6-cut management in 1990. The opposite was true for 1991, with the 6-cut system transferring 8% less fixed-N. Total-
season N transfer from the 6-cut system of RC was greater by 41 and 4% for 1990 and 1991, respectively. None of these differences were significant (P≤0.05), however.

Nitrogen transfer from BT and RC tended to be related negatively to legume proportion in the mixtures for both harvest management systems in both years. Typically, a larger yield of fixed-N (resulting from a greater legume proportion) would correlate with increased %Ngdfa. As explained, previously, a consequence of the isotope dilution technique is that this technique does not discriminate between N₂ fixed in different years. Therefore, there would tend to be a lag in the time of detection of N transfer to associated grass. When legume proportions were high, the slow mineralization of released N from the legume would depict a low transfer of fixed-N to the associated grass.

Three-cut system transferred-N yields from OG grown with BT were 18% greater in 1991 than in 1990. Six-cut system transferred-N yields from OG grown with BT, however, were 25% greater in 1990 than in 1991. Transferred-N yields from OG grown with RC were greater in 1991 for both harvest managements. Mean TNYs for 1991 were 59 and 30% greater than 1990 TNYs for 3-cut and 6-cut systems, respectively. Transferred-N yields from OG grown with BT and RC tended to be related negatively to legume proportion in the mixtures for both harvest management systems in both years. Mallarino et
al. (1990) reported that by increasing legume proportion, TNY either was not affected or decreased. Typically, a larger DM yield from grass (resulting from a reduced legume proportion) would correlate with increased TNY. For the BT 6-cut system, the last three harvests of 1990 yielded a mean TNY of 10.1 kg ha$^{-1}$ (42% of total) compared to only 3.2 kg ha$^{-1}$ (18% of total) for the last three harvests of 1991. Similarly, the last three harvests of 1990 yielded 25% more OG DM than the last three harvests of 1991. Thus, the decreased OG DM yields of the BT 6-cut system for the latter part of 1991 resulted in a reduction in overall yield of transferred-N.

The BT 6-cut system for 1990 always yielded more transferred-N in associated OG, however, only OG-DWN and OG-NOR showed significant (P<0.05) differences between management systems. In 1991, the BT 3-cut system always yielded more transferred-N in associated OG than the 6-cut system, although differences between management systems were not significant (P<0.05) for any mixture. This follows the findings by Mallarino et al. (1990). Here, BT legume proportions for the two management systems in both years changed minimally and TNY remained virtually the same or decreased.

The RC 6-cut system for both years usually yielded more transferred-N in associated OG, however, differences between management systems were not significant (P<0.05). As was reported by Mallarino et al. (1990), mean RC legume
proportions for the 3-cut system in both years were greater than mean legume proportions in the 6-cut system. As a result, mean TNYs were slightly greater for the 3-cut system.
SUMMARY AND CONCLUSIONS

Experiment One

An isotope dilution study was conducted in the field with the primary objective of determining if differences exist among BT and RC cultivars in terms of $N_2$ fixation and N transfer capabilities. Four BT and four RC cultivars were seeded in mixture with OG. Birdsfoot trefoil cultivars tested were APB-8701 (experimental), Dawn, Fergus, and Norcen. Red clover cultivars tested were APR-8701 (experimental), Arlington, Mammoth, and Redland II. The BT and RC experimental cultivars were selected for improved $N_2$ fixation capabilities. The OG cultivar Dawn was used in the mixtures and as the nonfixing control for the isotope dilution study. A small amount of a $^{15}$N-labelled fertilizer was applied to each plot. Three harvests were taken in each of two years. The harvested material was separated into legume and grass fractions, dried, ground, analyzed for total N concentration, analyzed for isotopic composition by mass spectrometry, and calculations were performed to estimate $N_2$ fixation and N transfer amounts for the different cultivars. Dry matter yields for both BT and RC were suppressed by the dry conditions experienced in 1989. Improved moisture conditions in 1990 increased DM yields appreciably. The BT cultivar APB-
8701 usually was the lowest yielding of the four tested, although these differences were not significant in all harvests. Legume proportions in the mixtures usually did not differ, which shows the four BT cultivars exhibit similar persistence in the field. The RC cultivar Mammoth usually was the lowest yielding of the four RC cultivars tested. This was not surprising as Mammoth is typically regarded as a lower yielding cultivar. Legume proportions of the four RC cultivars usually did not differ in 1989. In 1990, however, legume proportion in the mixture for Mammoth declined significantly. This is not uncommon for Mammoth, also, as the alteration of the root system, as well as the regrowth characteristics of this "one-cut" RC, tend to lower productivity.

Dinitrogen fixation usually did not differ among any of the BT or RC cultivars in either year. Dinitrogen fixation tended to be greater in 1990 than in 1989. This reflects the dry conditions of 1989 which limited herbage DM yield. Previous studies have shown that large amounts of photosynthetic tissue are required to support high N₂ fixation. Legume proportions were lower for 1990 for both BT and RC. Previous studies have shown, also, that as legume:grass ratios decrease, N₂ fixation is stimulated as the grass depletes the soil of available N. Fixed-N yields were best described by legume DM yield. Yields of fixed-N in BT
herbage usually did not differ in either year. Yields of fixed-N in RC herbage usually did not differ in 1989, however, Mammoth usually had a lower yield of fixed-N in 1990. This reflects the decreased legume DM yield for Mammoth in 1990.

Nitrogen transfer from either BT or RC to associated OG did not differ among cultivars in either year. Nitrogen transfer from both BT and RC tended to be greater for 1990 than 1989. This is most likely the result of the dry conditions of 1989 which would limit decomposition and mineralization of legume residues. This consequence tends to be a limitation for the isotope dilution technique.

Dinitrogen fixed in one growth period may not be detected as transferred-N until a later period. Transferred-N yields did not differ among OG grown in association with cultivars of either BT or RC. Yields of transferred-N in associated OG reflected OG DM yields. Transferred-N yields for both BT and RC were greater in 1990, when OG DM yields were greater and legume proportions in the mixtures were less.

The BT cultivars tested all performed similarly. The experimental cultivar APB-8701 did tend to be lower yielding in terms of DM production, however, N\textsubscript{2} fixation and N transfer to associated OG was very similar among all four cultivars. The RC cultivars tested performed comparably in 1989. In 1990, however, Mammoth yielded less herbage DM. This reduction in DM yield for Mammoth did not affect its ability
to fix atmospheric $N_2$ or to transfer fixed-$N$ to associated OG. The RC experimental cultivar (APR-8701), Arlington, and Redland II were all comparable in DM production, $N_2$ fixation, and $N$ transfer to associated OG.

Experiment Two

An isotope dilution study was conducted in the field with the primary objective of determining how harvest management affects the amounts of $N_2$ fixation and $N$ transfer from BT and RC cultivars. Four BT and four RC cultivars were seeded in mixture with OG. Birdsfoot trefoil and RC cultivars tested, as well as the OG cultivar used in the mixtures, were the same as used in Exp. 1. A small amount of a $^{15}N$-labelled fertilizer was applied to each plot. Two harvest managements were imposed on the BT and RC mixtures, a moderate system (three harvests per season) and a severe system (six harvests per season). The harvested material was separated into legume and grass fractions, dried, ground, analyzed for total $N$ concentration, analyzed for isotopic composition by mass spectrometry, and calculations were performed to estimate $N_2$ fixation and $N$ transfer amounts for the different cultivars.

Herbage DM yields for the BT/OG mixtures under both management systems were greater in 1990 than in 1991. Legume proportions in the mixtures tended to be greater than 50% for
both management systems in 1990. The 3-cut system always yielded a greater amount of total herbage DM for both years. Birdsfoot trefoil plants subjected to the 3-cut system had more stem growth which contributed to increased DM yields. Herbage DM yields for the RC/OG mixtures were greater for 1990 under the 3-cut system but were similar for the two years under the 6-cut system. Mean RC legume proportions in the mixtures did not change much between the two years for either management system, with the exception of Mammoth. Red clover herbage DM yields for the 3-cut system were always greater than the 6-cut system for 1990. The two management systems tended to be comparable in total DM yield for 1991.

Dinitrogen fixation by BT cultivars was always greater under the 3-cut management than under the 6-cut management. The frequent removal of photosynthetic tissue (as in the 6-cut system) forces the nodules to compete with vegetative growth for reserve carbohydrates and adversely affects $N_2$ fixation. Fixed-N yields reflected BT DM yields and usually did not differ among cultivars for either management system in either year. Yields of fixed-N were greater in 1990 than in 1991 for both systems, largely the result of greater yield of legume in the mixture in 1990. Total FNYs did not differ between harvest managements for any of the cultivars in either year.

Dinitrogen fixation by RC cultivars tended to be greater under the 6-cut management than under the 3-cut management.
The competition for reserve carbohydrates between nodules and vegetative material does not appear to be as great for RC as differences between management systems were small or nonsignificant in most cases. Fixed-N yields were greater in 1990 when legume DM yields were greater. Yields of fixed-N for RC usually did not differ between harvest management systems.

No differences in N transfer were shown among harvest management systems for any of the BT or RC mixtures. Nitrogen transfer was greater in 1990 when legume proportions in the mixtures were greater. Transferred-N yields reflected OG DM yields and tended to be greater in 1991. Harvest management systems usually did not affect TNYs among any of the BT or RC mixtures for either year.

Harvest management affected DM yields of both BT and RC mixtures. Dinitrogen fixation by BT was also affected by harvest management. Harvest management did not appear to affect the amount of N transfer from either BT or RC to associated OG. It is possible that other factors may be involved that would result in an underestimation of N transfer. These factors would include microbial activity in the soil, temperature and moisture (which would affect microbial activity in the soil), and N status of the soil. The isotope dilution technique is unable to account for these
factors and, thus, N transfer may appear to be lower or may occur at a later time.
LITERATURE CITED


Butler, G. W., and N. O. Bathurst. 1956. The underground transfer of nitrogen from clover to associated grass. p.


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Table A1. Mean dry matter yield, mean total N concentration, and mean \(^{15}\text{N}%\) atom-excess in herbage of reference orchardgrass for Experiment One

<table>
<thead>
<tr>
<th>Year</th>
<th>HA</th>
<th>Mix</th>
<th>DM</th>
<th>N</th>
<th>(^{15}\text{N})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
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<td>BT/OG</td>
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<tr>
<td></td>
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<tr>
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<tr>
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<tr>
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<td>0.68</td>
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</tr>
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</table>

\(^{a}\text{H} = \text{harvest.}\)

\(^{b}\text{Mix} = \text{mixture. BT/OG = birdsfoot trefoil/orchardgrass; RC/OG = red clover/orchardgrass.}\)

\(^{c}\text{DM} = \text{dry matter yield in Mg ha}^{-1}.\)

\(^{d}\text{N} = \text{percentage total N in orchardgrass herbage.}\)

\(^{e}\text{\(^{15}\text{N}\) = \(^{15}\text{N}%\) atom-excess in orchardgrass herbage.}\)
Table A2. Mean dry matter yield, mean total N concentration, and mean $^{15}$N %atom-excess in herbage of reference orchardgrass for Experiment Two

<table>
<thead>
<tr>
<th>Year</th>
<th>H</th>
<th>Mgt</th>
<th>Mix</th>
<th>DM</th>
<th>N</th>
<th>$^{15}$N</th>
</tr>
</thead>
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$^a$H = harvest.

$^b$Mgt = harvest management system. A = 3-cut system; B = 6-cut system.

$^c$Mix = mixture. BT/OG = birdsfoot trefoil/orchardgrass.

$^d$DM = dry matter yield in Mg ha$^{-1}$.

$^e$N = percentage total N in orchardgrass herbage.

$^{15}$N = $^{15}$N %atom-excess in orchardgrass herbage.
Table A3. Mean dry matter yield, mean total N concentration, and mean $^{15}$N %atom-excess in herbage of reference orchardgrass for Experiment Two

<table>
<thead>
<tr>
<th>Year</th>
<th>H</th>
<th>Mgt</th>
<th>Mix</th>
<th>DM</th>
<th>Ne</th>
<th>$^{15}$N</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

$^a$H = harvest.

$^b$Mgt = harvest management system. A = 3-cut system; B = 6-cut system.

$^c$Mix = mixture. RC/OG = red clover/orchardgrass.

$^d$DM = dry matter yield in Mg ha$^{-1}$.

$^e$N = percentage total N in orchardgrass herbage.

$^{15}$N = $^{15}$N %atom-excess in orchardgrass herbage.