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SUMMARY

Developing and maintaining profitable and sustainable agricultural enterprises requires discovering and evaluating new management practices, and reassessing those formerly used. Rotating grains with forage legumes is an old and established practice, but prone to change with the development of new legume varieties.

The technology of crop rotations is itself changing. One example is the potential of using "annual" alfalfa (nondormant varieties managed as annual crops for one year) in cropping systems. This bulletin presents results from 10 years of research on the use of annual alfalfas in the upper Midwest.

Our research shows that including an annual alfalfa for seeding year production of forage and nitrogen (N) in rotations can increase grain yields and economic returns from subsequent crops, through N and non-N rotation effects. The alfalfa N contributions to a subsequent crop are influenced by factors which include harvest management, the environment, and the dormancy characteristics of any given variety.

This bulletin also discusses a new nondormant alfalfa variety, Nitro, specifically developed in Minnesota to maximize forage yield during the seeding year and to supply N in crop rotations. The profitability and N contribution of Nitro in short-term rotations is influenced both by the establishment method and crop harvest management.

INTRODUCTION

Forage legumes have long been important components of traditional Corn Belt crop rotations. Forage legumes promote the growth of subsequent crops, reduce soil erosion, and provide feed for livestock.

Legume benefits to subsequent crops are attributed to the addition of nitrogen (N), and to non-N rotation factors such as disease and weed control, and improved soil water holding capacity. Organic and sustainable agricultural enterprises, which typically have a greater proportion of cropland in forages than do conventional enterprises, also have lower rates of soil erosion, lower energy consumption, and lower production costs than conventional enterprises (Lockeretz *et al.*, 1984).

Widespread use of forage legume-based crop rotations has declined since the 1930s. In 1930, there was approximately 1.25 acres of alfalfa (*Medicago sativa* L.) and clover (*Trifolium* spp.) for each acre of corn (*Zea mays* L.) in the principal corn growing region of Minnesota. By 1979 there was only 0.75 acre of alfalfa and clover per acre of corn (Cardwell, 1982). Sweet clover (*Melilotus* spp.), used as a green manure on approximately 750,000 acres in the 1940s, is currently grown for green manure to only a limited extent.

The decline in use of forage legumes in rotations was associated with the development of the inorganic N fertilizer industry following World War II, and with the subsequent availability of inexpensive N fertilizers such as anhydrous ammonia. Farm enterprises also became less diversified and forage legumes once used to feed livestock were not needed.

Interest in the use of forage legume-based crop rotations has revived in recent years because of increased emphasis on low input sustainable agricultural practices, and because of government cropland diversion programs (Heichel and Barnes, 1984).

A traditional Midwestern crop rotation includes oat (*Avena sativa* L.)-alfalfa in year one, alfalfa for two or more years, and a row crop for one or more years. Conversion to this traditional rotation may be impractical for grain producers who currently do not use forage legumes to feed animals and who generate all or the majority of their income from grain production. An alternate would be to manage the forage legume as an annual crop by early spring establishment, plowing it into the soil in the fall or subsequent spring. Frequency and number of harvests would vary depending on the relative need for on-farm forage, the potential for selling hay, or the need to provide N for subsequent crops.

Annual forage legumes once were commonly used for green manures in crop rotations. Nondormant alfalfas managed as annual crops were the subject of considerable Corn Belt research during the 1950s (Fribourg and Johnson, 1955; Kroontje and Kehr, 1956; Smith, 1956; Stickler and Johnson, 1959). Recent development of the special-purpose nondormant alfalfa variety, 'Nitro' (Barnes et al., 1988), provided an opportunity to agronomically evaluate the use of annual alfalfas in contemporary crop rotations.

Nitro is intended for use in the upper Midwest as hay and silage, and as a source of N for subsequent agronomic and horticultural crops when it is grown for just one year.

In this report, we discuss using nondormant alfalfa as an annual crop in short-term rotations. We also discuss attributes and use of nondormant alfalfas. Our special emphasis is on the development, evaluation, and management of the recently released special-purpose variety, Nitro.

ALFALFA AFFECTS YIELD OF SUBSEQUENT CROPS IN ROTATION

Including one year of alfalfa in rotations at four Minnesota locations consistently increased subsequent corn yields compared to continuous corn cropping or corn-soybean [Glycine max (L.)

Table 1. Corn grain yields following one year of alfalfa, soybeans, or corn at four Minnesota locations. No N fertilizer applied.[1]

First year crop		Corn grain yield (bu/acre)				
		Becker	Lamberton	Rosemount	Waseca	Location mean
Alfalfa [2]	3-cut [3]	87	113	125	80	101
	1-cut [4]	97	114	134	115	115
Corn		56	81	51	49	59
Soybean		64	107	94	59	81
LSD (0.05)		24	22	33	22	25

1. Adapted from Hesterman et al. (1986a).
2. Averaged for MN Root-N (Nitro predecessor) and Saranac AR.
3. Two summer and one fall harvest; crowns and roots incorporated in fall.
4. One summer harvest; herbage regrowth, crowns, and roots incorporated in fall.

Merr.] rotations when no fertilizer N was applied (Table 1). Averaged over locations, corn grain yields following one year of alfalfa were 95% and 42% greater, respectively, than those following corn and soybean.

The application of N fertilizer to corn usually decreases the effects of preceding crops in rotations. However, at Waseca, alfalfa enhanced corn yields at N fertilizer rates of 50 to 200 lbs N/ acre (Table 2). The yield enhancement of corn following one- or three-cut alfalfa at an N rate which maximized continuous corn grain yields, as well as corn yields following soybean and wheat (*Triticum aestivum* L.), is evidence of non-N rotation effects.

Based on experimental results like those shown in Table 2, in which corn yield was measured following alfalfa, fertilizer-N replacement values of alfalfa were estimated. These values represented the amount of inorganic N fertilizer that would be required to produce an equivalent corn yield under comparable test conditions. For example, incorporation of a one-year-old stand of alfalfa managed in a three-cut system produced corn grain yields (no N applied) equivalent to those expected from 50 to 100 lbs N/acre applied to continuous corn (Table 2).

Fertilizer-N replacement values for alfalfa and soybean at several locations are shown in Table 3. Fertilizer-N replacement values for one-cut alfalfa are generally greater than those for three-cut alfalfa. The one-cut management provided 15% more N for plowdown in the fall than three-cut management (Hesterman et al., 1986a). In the three-cut management, only roots and crowns plus herbage stubble were incorporated. Fertilizer-N replacement values for alfalfa in Minnesota usually exceed those for soybean, because a net increase in soil N status

Table 2. Corn grain yields as influenced by previous crop and N fertilizer rate at Waseca, Minnesota. [1]

N rate (lbs/acre)	Corn grain yield (bu/acre) following 1 year of:				
	Corn	Soybean	Wheat	3-cut alfalfa [2,4]	1-cut alfalfa [3,4]
0	50	58	57	80	115
50	65	90	99	124	137
100	100	122	128	137	139
150	103	138	127	138	138
200	100	140	144	145	145

1. Adapted from Hesterman et al. (1986a).
2. Two summer and one fall harvest; crowns and roots incorporated in fall.
3. One summer harvest; herbage regrowth, crowns and roots incorporated in fall.
4. Averaged for MN Root-N (Nitro predecessor) and Saranac AR.

Table 3. Fertilizer-N replacement values for corn following one year of alfalfa and soybeans at four Minnesota locations. [1]

First year crop	Harvest system	Fertilizer-N replacement values (lbs N/acre)				
		Becker	Lamberton	Rosemount	Waseca	Location mean
Alfalfa [2]	3-cut [3]	47	91	125	84	87
	1-cut [4]	64	93	131	190	120
Soybean [5]		2	75	48	26	38

1. Adapted from Hesterman and Sheaffer (1984).
2. Averaged for MN Root-N (Nitro predecessor) and Saranac AR.
3. Two summer and one fall harvest; crowns and roots were incorporated in fall.
4. One summer harvest; herbage regrowth, crowns and roots were incorporated in fall.
5. Hodgson 78 soybeans were harvested for grain. Values are for residue (stems, leaves, and roots).

seldom occurs with soybean grain production (Heichel, 1987).

In the Minnesota soil testing program (Rehm *et al.*, 1986), fertilizer-N replacement values are generalized for the entire state. For example, when corn yield goals are greater than 175 bu/acre on soils with low to medium organic matter content, incorporation of a "good" and a "poor" alfalfa stand is equivalent to the application of 100 and 60 lbs N/acre, respectively.

Fertilizer-N replacement values represent the combined N and non-N effects of alfalfa on a subsequent crop. In the following section, we will distinguish between legume N effects and non-N rotation effects on yields of subsequent crops.

NITROGEN FROM ALFALFA

Alfalfa uptake of soil N

Nitrogen contributed by alfalfa, for use by subsequent crops in rotations, originates from the uptake of soil N or from biological N_2 fixation (BNF) (Figure 1). The contribution of BNF-derived N in legume residue to the soil depends on the amount of BNF and on the amount and type of residue left in the soil.

The availability of soil N has a major effect on the BNF-derived N content in alfalfa herbage and roots. Alfalfa grown on low organic matter, N-poor soils generally contains greater proportions of BNF derived-N than alfalfa grown on high organic matter or N-fertilized soils. The incorporation of alfalfa herbage and roots which primarily contain soil-derived N results only in N recycling and does not produce a net increase in the amount of soil N.

Biological N_2 fixation

Biological N_2 fixation occurs through a symbiotic association of alfalfa with a host specific bacterium (*Rhizobium meliloti*) which causes growth of nodules on lateral roots (Figure 2). The plant supplies energy and nutrients to this bacterium. The bacterium reduces gaseous N_2 from the soil atmosphere into ammonium ions available to the plant. The plant subsequently converts the ammonium ions into amino acids which are used for protein synthesis (Vance, 1978; Heichel, 1985).

Nitrogen fertilization generally is not beneficial to alfalfa productivity unless nodule formation is impaired by low soil pH or by lack of effective N_2 fixing bacteria.

Effect of alfalfa harvest management

Alfalfa harvest management has a major effect on the contribution of BNF-derived N to the soil. Since alfalfa herbage usually contains both N derived from BNF and N from the soil (Figure 1), frequent removal of herbage may deplete soil N. Consequently, the proportional contribution of BNF-derived N and the total amount of BNF-derived N added to the soil by alfalfa will be

Figure 1. Three regimes for N nutrition of alfalfa. The left panel represents a regime with all crop N derived from the soil and none from symbiotic N_2 fixation. The right panel represents a crop growing on N-impoverished soil, solely dependent on symbiotic N_2 fixation. The center panel represents the typical Midwestern regime, with alfalfa obtaining N from both soil and biological N_2 fixation.

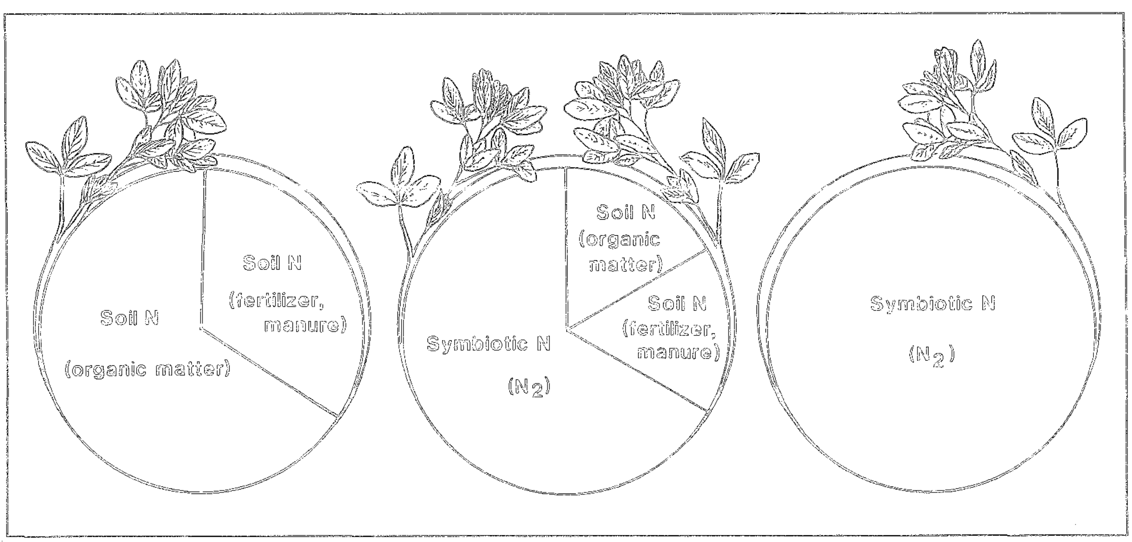
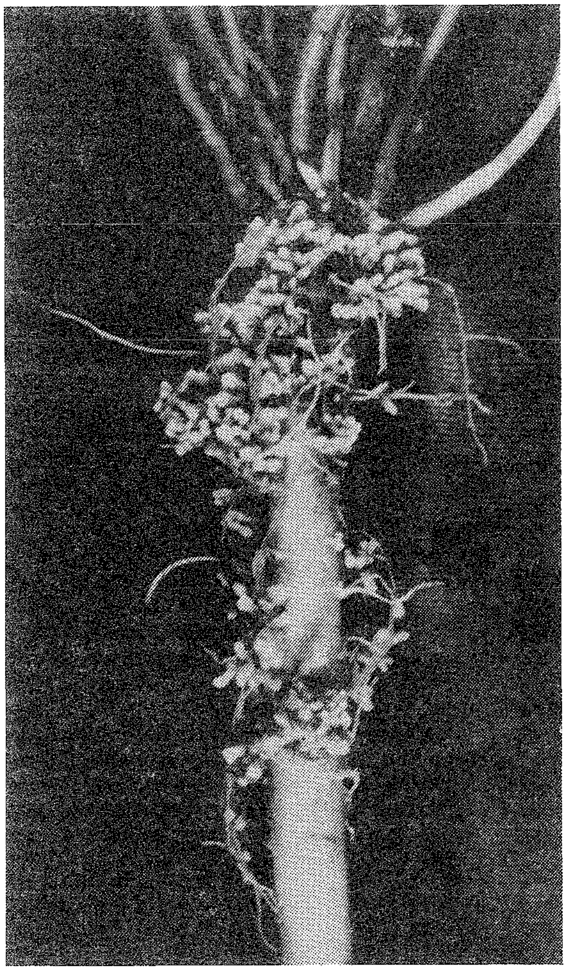


Figure 2. Nodules on alfalfa roots. Nodules are the site of biological N_2 fixation and are formed by the interaction of a soil bacterium and alfalfa.



increased if forage as well as roots (including crowns) are incorporated in the fall.

This is illustrated in Table 4 by comparing the BNF-derived N incorporated in one- and three-cut harvest systems. The one-cut system, in which herbage regrowth and roots plus crowns were incorporated in the fall, resulted in the addition of 37% more BNF-derived N compared to the three-cut system, in which only roots plus crowns were incorporated.

ROTATION EFFECT

Yield enhancement not directly associated with legume N contribution is called a rotation effect (Baldock *et al.*, 1981). Russelle *et al.* (1987) reports that rotation effect accounted for about 25% of the yield response of unfertilized (no N) corn following one-year of alfalfa on a fine-textured soil, and about 80% of the yield response when 150 lbs N/acre were applied.

The rotation effect is evident in comparisons of corn yields following a non-N_2 fixing crop with yields from continuous corn. Corn yields for the wheat-corn rotation are 14% to 44% greater than for continuous corn. The importance of the rotation effect is also evident in enhanced corn yield following a soybean crop. (Table 2)

The benefit of soybean in rotation with corn is commonly expressed as "1 lb N/bu soybean yield" (Voss and Shrader, 1984). However, harvesting soybean grain usually removes considerable soil N (Heichel, 1987) and stem, leaf, and root residue returned to the soil

Table 4. Fall legume root and forage dry matter (DM) yields, and incorporated N from biological N_2 fixation at Becker, MN. [1]

Legume	Harvest system	DM yields (lbs/acre) Root [2]	DM yields (lbs/acre) Forage	BNF-N incorporated (lbs/acre) Root	BNF-N incorporated (lbs/acre) Forage	BNF-N incorporated (lbs/acre) Total
Alfalfa [3]	3-cut [4]	3600	—	76	—	76
	1-cut [5]	3800	2600	68	36	104
Soybean [6]	grain	—	162	—	—	13

1. Adapted from Hesterman *et al.* (1986a, 1987).
2. Root consists of root, crown, and stubble.
3. Averaged for MN Root-N (Nitro predecessor) and Saranac AR.
4. Two summer and one fall harvest; crowns and roots were incorporated in fall.
5. One summer harvest; herbage regrowth, crowns and roots were incorporated in fall.
6. Hodgson 78 soybean was harvested for grain. Values are for residue (stems, leaves, and roots).

contains only small amounts of biologically fixed N (Table 4). Consequently, soybean production often results in only small additions of fixed N, or may result in net losses in soil N (Heichel and Barnes, 1984). It is apparent that yield benefits derived from soybean use in rotations in Minnesota are often due primarily to the rotation effect and not to N addition.

The rotation effect may have several causes. One source of the alfalfa rotation effect is an improvement in soil tilth and water holding capacity following incorporation of alfalfa plant materials. General rotation effects for many crop species have been attributed to reduced insect, disease and weed infestation; and elimination of autotoxic substances in crop residues (Barber, 1972). Incorporated alfalfa herbage may release growth promoting substances such as triacontanol (Ries *et al.*, 1977).

In summary, alfalfa affects the yield of subsequent crops in rotation through contributions of N, organic matter, and other less understood rotation factors. In practice, the greatest and most consistent direct benefits of alfalfa to the yield of subsequent crops can be achieved through management of the N effect. Improvement in soil physical properties and disruption of pest cycles are also important contributions, but they are less easily managed.

ECONOMIC EFFECTS

Analyzing two-year rotation studies conducted at four Minnesota locations showed that an alfalfa-corn rotation, with alfalfa grown, harvested, and incorporated in the seeding year, was consistently more profitable than continuous corn or soybean-corn rotations (Table 5). When long range cost/price planning situations were altered, the alfalfa-corn rotation still was the most profitable.

The superior profitability of the alfalfa-corn rotation is determined by the quantity and quality of the forage produced, and to a lesser extent by the effect of alfalfa on the yield of the subsequent corn crop (Hesterman *et al.*, 1986b). Along with the potential for increased profitability, introducing a legume into a continuous cropping system reduces financial risk and uncertainty. However, a diversified cropping system requires both a larger array of

Table 5. Effect of first-year crops and N application to corn grown following first-year crops on two-year gross margin at long-range planning prices at four Minnesota locations.[1]

Location	First-year crop	N application [2] (lbs/acre)	Two-year gross margin [3] ($/acre)
Becker	Alfalfa [4]	150	644
	Corn	150	599
	Soybean	150	534
Lamberton	Alfalfa	0	503
	Corn	40	403
	Soybean	120	454
Rosemount	Alfalfa	0	515
	Corn	0	500
	Soybean	50	360
Waseca	Alfalfa	200	526
	Corn	200	331
	Soybean	150	376

1. Adapted from Hesterman *et al.* (1986b). Long-range planning prices for corn, soybean and N fertilizer were $2.80/bu, $6.79/bu, and $0.25/lb. Alfalfa forage production was valued based on crude protein (CP) and total digestible nutrient (TDN) yield when CP = $0.20/lb and TDN = 0.05/lb.
2. N fertilizer rate applied to corn grown following first-year crops which resulted in the highest gross margin for the associated first-phase component.
3. Gross margin is defined as revenue minus the related cash expenses, and it implies the return to land, machinery, labor, and other overhead.
4. Alfalfa established in spring, harvested three times in the seeding year, and roots and crowns incorporated.

production equipment and broader knowledge regarding the production of several crops compared to sole cropping.

NITRO: A NONDORMANT ALFALFA FOR SHORT-TERM ROTATIONS

The volatility of manufactured N fertilizer prices and the need to develop technologies to increase the sustainability of cropping systems led USDA-ARS and University of Minnesota scientists to study the potential for enhancing the N_2-fixing ability of alfalfa. A project was initiated in 1977 to breed a nondormant alfalfa with increased N accumulation capability in the roots.

Crop management studies of the improved nondormant population began in 1982 when seed first became available. This cooperative breeding and crop management effort led to the release of the variety "Nitro" (Barnes *et al.*, 1988). Nitro was the first alfalfa variety with unique N accumulation and agronomic characteristics specifically developed for use in contemporary upper midwestern cropping systems that utilize only one (seeding) year of alfalfa production.

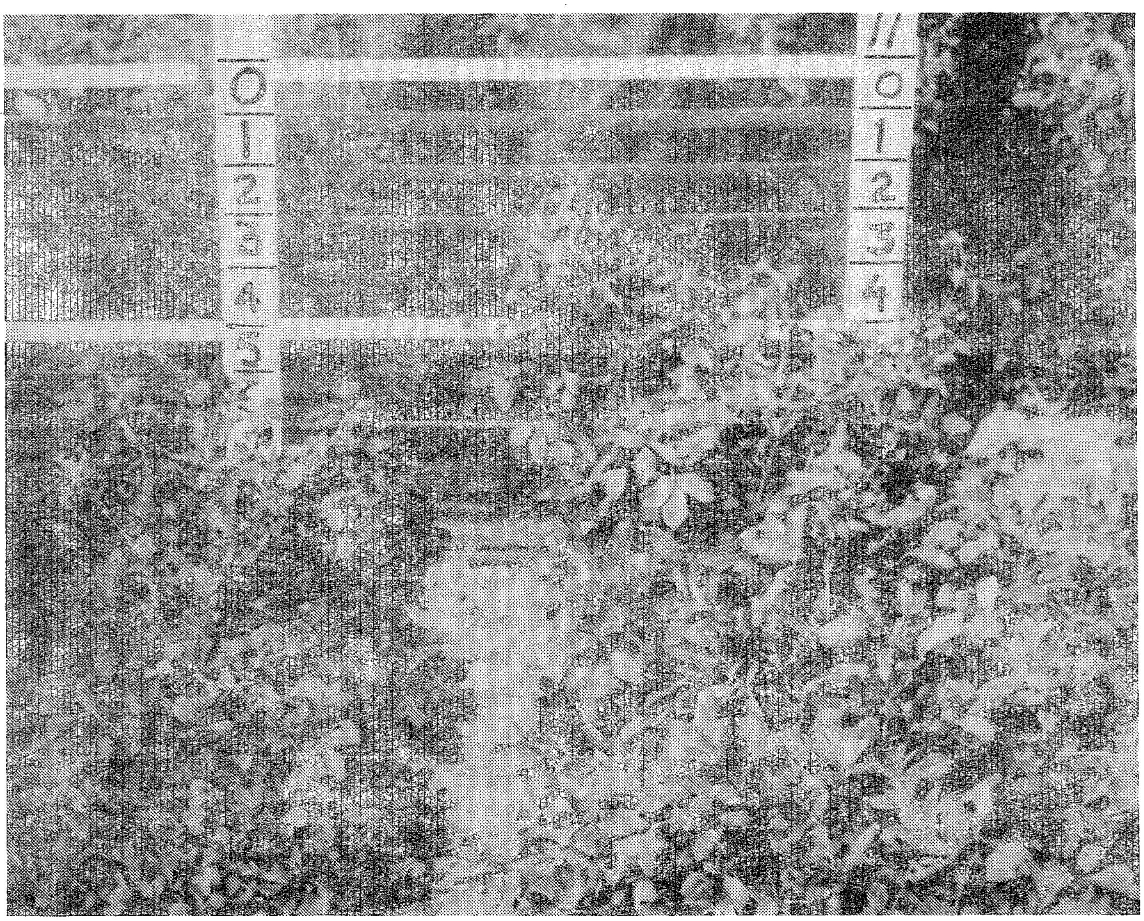
BREEDING NITRO

Choosing parental germplasm

Three unrelated germplasm sources were used in the breeding program: UC Cargo, a very nondormant variety with very rapid regrowth after cutting, developed by the University of California; SW Comp AN4P3, a nondormant, multiple pest resistant population developed by the USDA-ARS at Reno, NV; and BIC, a genetically broad, semidormant population developed by the USDA-ARS at Beltsville, MD. The BIC population was deleted from the program because dormancy characteristics reduced its fall forage yield compared to UC Cargo and SW Comp AN4P3.

Nondormant alfalfa varieties contrast with

Figure 3. Dormant (left) and nondormant (right) alfalfa in the fall. In the fall, dormant alfalfa varieties have reduced herbage production compared to nondormant varieties.



standard dormant and moderately dormant varieties used in Minnesota. In the fall, dormant varieties respond to the decreasing day length and cool temperatures by storing energy as root carbohydrates. Herbage production is reduced compared with nondormants (Figure 3).

Since nondormant varieties like Nitro store few reserves for the winter, forage production and N_2 fixation may continue for four to six weeks longer in the fall than for dormant varieties. These nondormant alfalfas have the potential to maximize seeding year forage production, but they will not reliably overwinter in Minnesota without long-term snow cover and should be considered annuals.

Breeding procedures

A summarizing chronology of the breeding of Nitro is presented in Table 6.

The first two cycles of selection were conducted in the field at Rosemount, MN. In each cycle about 15,000 plants/population were seeded in rows (15 seed/ft) in early May (Barnes *et al.*, 1988). The plants were clipped on July 15 and August 30. On October 20, all plants were undercut and 30%, those with the largest shoot growth, least leaf disease injury, and least frost injury, were removed from the soil.

The 3,750 plants/population extracted from the soil were examined for root size and 400 plants with the largest roots were selected. The lower portion of the root was removed and analyzed for N concentration. The crown plus upper root portion of each plant was planted in the greenhouse. The 125 plants in each population with the greatest root N concentration were intercrossed.

Simultaneous selection for large shoots, large roots, high root N concentration, and healthy fall foliage insured that only superior plants were chosen. The procedures were effective for increasing root and crown mass and plant N concentration (Table 7). Subsequent studies at the University of California demonstrated that a similar program of simultaneously selecting for both high forage yield and high forage N concentration was effective for increasing forage yield and crude protein concentration (Teuber and Phillips, 1988).

Selection for resistance to foliar pathogens [primarily common leafspot caused by *Pseudopeziza medicaginus* (Lib.) Sacc.] and rust caused by *Uromyces striotus* schroet. was conducted in Salinas, CA during 1980. This was important because most nondormant germplasm sources are very susceptible to foliar diseases common in the upper Midwest. Diseased foliage

Table 6. Activities in the field selection and evaluation of nondormant alfalfa germplasm for summer hay production, and residual N production in Minnesota.

Year	Activity
1977	First cycle recurrent phenotypic selection in three germplasm sources for high fall herbage yield, reduced foliar disease, and frost injury, large crown and root mass, and root N concentrations. MnN_1 germplasms produced.
1979	Second cycle recurrent phenotypic selection in three N_1 germplasms for the same traits. MnN_2 germplasms produced.
1980	Selection for common leafspot (CL) resistance in MnN_2 germplasms in Salinas, CA. MnN_2CL germplasms produced.
1981	Intercrossed three MnN_2CL germplasms to produce three strain crosses.
1982	First field tests conducted to evaluated MnN_2, strain crosses, and parental populations. MNSW x UC chosen as best population.
1983	Large scale seed increase of MNSW x UC (experimental designation of best nondormant germplasm).
1984	Field tests of MNSW x UC for dry matter production and N_2 fixation at four Minnesota locations, and for dry matter production at seven out-of-state locations.
1986	Release of special purpose "Nitro" cultivar.

increases the severity of frost injury in the fall.

The improved populations from the UC Cargo and SW Comp AN4P3 germplasms were intercrossed to develop a superior population having characteristics of both parents and providing a broad gene base to minimize inbreeding in advanced generations.

Evaluation

Nitro and a small number of standard nondormant and dormant varieties were tested at several Minnesota locations from 1982 to 1985. It was necessary to: characterize the production of nondormant alfalfa in Minnesota, which is outside the area of adaptation (southwest USA); determine the economic potential of a one-year alfalfa cropping system; and determine the effect of cutting management on forage and N yields.

Summer forage yields were similar for Nitro and standard nondormant and dormant alfalfa varieties, but fall forage production of Nitro and the standard nondormant varieties exceeded that of the dormant varieties by about 70% (Table 8).

At latitudes with milder winters, nondormant alfalfas may overwinter and act as true perennials. For example, in Oklahoma, Nitro has been among the more productive varieties in the second and third years of production trials (Unpublished data from Dr. J.L. Caddel, Dept. of Agronomy, Oklahoma State University, Stillwater, OK).

Root size of Nitro and other nondormant varieties, illustrated in Figure 4, was greater than with dormant varieties. Nitro had 4% greater concentration of N in the roots than standard nondormant and 13% greater than dormant

Table 7. Response of two nondormant alfalfa populations to two cycles of selection for increased shoot and root weight and high root N concentration as measured at a late October harvest. [1]

Entry	Root weight (g/plot)	Crown weight (g/plot)	Plant N (percent)
SW Comp (Original)	46.5	20.1	2.60
MN SW Comp (2nd cycle)	60.1	26.2	2.71
UC Cargo (Original)	32.4	16.9	2.84
MN UC Cargo (2nd cycle)	50.8	23.7	3.05
LSD (0.05)	12.2	6.1	0.10

1. Adapted from Heichel and Barnes (1984).

Table 8. Summer, fall, and total forage dry matter (DM) yields, and root DM yields of Nitro and nondormant and dormant varieties averaged over four Minnesota locations.

Entry [1]	Forage (ton DM/acre) Summer	Forage (ton DM/acre) Fall	Forage (ton DM/acre) Total	Roots (ton DM/acre)
Nitro	3.4	0.8	4.2	0.7
Nondormant varieties [2]	3.4	0.7	4.1	0.7
Dormant varieties [3]	3.4	0.4	3.8	0.6
LSD (0.05)	0.3	0.1	0.3	0.1

1. Entries established using a herbicide in late April and harvested three times at bud by early September (summer yield). Fall herbage and root DM yields determined in mid-October.
2. Mean of three representative varieties (CUF-101, Mesa-Sirsa, Moapa 69).
3. Mean of two representative varieties (Iroquois, Saranac AR).

varieties (Table 9). Nitro also had a greater N concentration in the crown than either the dormant or nondormant varieties.

The greater N concentration in the forage of Nitro compared to the other nondormant varieties may be associated with the improved fall foliar disease resistance of Nitro.

The greater forage, crown, and root yield; the higher concentration of total reduced N in the root; and the longer growth duration of the nondormant varieties were associated with the accumulation of 68% more biologically fixed N, compared to dormant varieties, between the last hay harvest and fall plowdown of the stands (Table 10).

Biological N_2 fixation varied among locations due to differences in residual soil N and growing conditions. For example, on the sandy loam at Becker, soil organic matter and residual soil N are lower than for silt loam soils at Waseca and Rosemount. Therefore, N_2 fixation was greater at Becker than at the fertile Waseca and Rosemount locations.

Figure 4. Nondormant Nitro (right) and a dormant alfalfa (left) in the fall. Nitro alfalfa was selected for increased root yield and increased root N concentration.

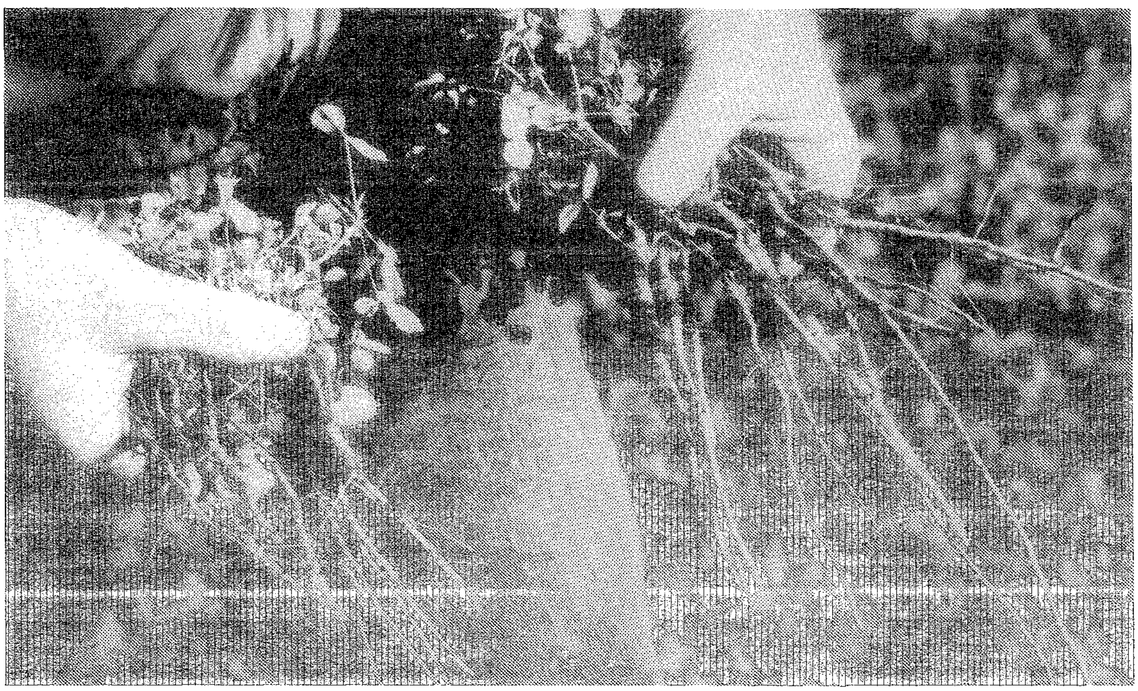


Table 9. Concentration of total reduced N in organs of Nitro and dormant and nondormant varieties at fall plowdown averaged over four Minnesota locations.

Entry [1]	Forage (percent N)	Crown (percent N)	Roots (percent N)
Nitro	3.9	2.9	2.7
Nondormant varieties [2]	3.7	2.8	2.6
Dormant varieties [3]	3.9	2.8	2.4
LSD (0.05)	0.1	0.1	0.2

1. Entries established using a herbicide in late April and harvested three times at bud by early September (summer yield). Fall forage and root DM yields determined in mid-October.
2. Mean of three representative varieties (CUF-101, Mesa-Sirsa, Moapa 69).
3. Mean of two representative varieties (Iroquois, Saranac AR).

Comparing Nitro, and the three other nondormant varieties, with dormant varieties demonstrated the increased fall growth generally associated with nondormant alfalfa (Tables 8, 9, and 10).

A trial comparing Nitro and 12 available nondormant varieties was conducted at Rosemount and Becker (Table 11). Nitro was among the best varieties for all traits. Nitro, Florida 77, Moapa 69, and Mesa-Sirsa were the best varieties for total season forage dry matter yield and fall crown and root N yield. Nitro and Florida 77 had greater fall foliar disease

Table 10. Biologically fixed N in roots and herbage of Nitro and nondormant and dormant varieties at fall plowdown of the legume stands at four Minnesota locations.

Entry [1]	Becker	Lamberton	Rosemount	Waseca	Mean
	lbs N/acre				
Nitro	130	109	67	69	94
Nondormant variety [2]	118	101	56	60	84
Dormant variety	64	75	36	48	56
LSD (0.05)	14	18	15	8	14

1. Entries established using a herbicide in late April and harvested three times at bud by early September (summer yield). Fall forage and root dry matter yields determined in mid-October.
2. See Table 8 for variety designations.

Table 11. Comparison of 13 nondormant varieties for dry matter (DM) yield, N, and disease resistance characteristics. All data are means of two trials conducted at Rosemount and Becker, MN.

Non-dormant varieties	Summer Forage Yield [1]	Fall Yield (ton DM/acre) [2]			Fall N Conc. (percent)		Fall N Yields Crown+root (lbs N/acre)	Disease Resistance Rating [4]		
		Forage	Crown	Root	Crown	Root		Foliar disease [3]	Phytophthora root rot	Fusarium wilt
Nitro	4.25	0.81	0.42	0.66	2.97	2.73	61	MR	R	HR
Ardiente	3.98	0.67	0.41	0.65	2.76	2.30	52	R	MR	R
Baron	4.22	0.73	0.38	0.59	2.61	2.38	48	R	R	R
Cibola	4.00	0.73	0.43	0.72	3.04	2.43	61	LR	MR	HR
CUF 101	4.09	0.72	0.38	0.59	2.87	2.63	53	S	MR	HR
DK 187	4.12	0.70	0.38	0.60	2.85	2.36	50	MR	R	HR
Florida 77	4.24	0.81	0.44	0.71	2.58	2.44	57	R	S	HR
Granada	3.99	0.73	0.41	0.56	2.73	2.60	51	LR	R	HR
Maxidor	3.82	0.70	0.42	0.67	2.92	2.51	59	S	MR	R
Mesa-Sirsa	4.28	0.83	0.39	0.56	2.75	2.41	49	S	S	HR
Moapa 69	4.18	0.76	0.43	0.71	2.95	2.53	61	LR	S	HR
Pierce	3.92	0.73	0.38	0.64	2.80	2.43	53	MR	R	HR
5929	3.96	0.71	0.42	0.63	2.99	2.66	59	S	R	HR
LSD (0.05)	0.30	0.08	0.06	0.09	0.13	0.18	8	—	—	—

1. Planted about May 1; summer harvests June 26, July 30 and September 5.
2. Fall harvest October 20.
3. Fall foliar disease score includes frost injury.
4. HR = high resistance, R = resistance, MR = moderate resistance, LR = low resistance, S = susceptible.

resistance than Moapa 69 and Mesa-Sirsa. However, of the best varieties for other traits, only Nitro had resistance to Phytophthora root rot (*Phytophthora megasperma* Drechs.). That resistance is a critical characteristic for most areas in the upper Midwest.

Considering all characteristics, Nitro appears to be the best available nondormant variety for use in Minnesota.

Table 12. Effect of establishment method on Nitro alfalfa forage and root dry matter (DM) and N yields, total (alfalfa + small grain) forage yields, and returns over costs in the seeding year. [1]

Establishment method [2]	Alfalfa yield (tons DM/acre)		Fall N yield (lbs N/acre)		Total Forage [5] (tons DM/acre)	Returns over costs[6] ($/acre)	
	Forage	Root	Forage	Root		Fixed	Cash
Solo-seeded (herbicide) [3]	2.8	1.1	36	73	3.2	2	130
Solo-seeded (no herbicide)	2.3	1.0	33	63	4.1	34	162
Rye companion crop	1.0	0.7	22	48	2.7	33	165
Oat-boot companion crop	1.1	0.8	29	50	2.9	-22	109
Oat-grain companion crop [4]	0.8	0.7	29	38	0.9	-13	113
LSD (0.05)	0.2	0.1	4	5	0.2	—	—

1. Adapted from Sheaffer *et al.* (1988b). Seeded April 15 at Rosemount, MN. Seeding rates: alfalfa (12 lb/acre), oat (48 lb/acre), rye (44 lb/acre).
2. Solo-seeded alfalfa treatments and rye and wheat companion crop treatments were harvested in early July, early August, and October; oat-boot-treatment was harvested in mid-June, early August and October; oat-grain treatment was harvested in mid-July, late August, and October.
3. Preplant incorporated herbicide (Balan) applied before alfalfa seeding.
4. Average oat grain and straw yields were 87 bu/acre and 2.0 tons/acre.
5. Includes yield of weeds, small grain forage and alfalfa.
6. Returns include forage (valued based on relative feed value) (Linn and Martin, 1985); straw; grain; and N available for incorporation. Costs used in calculations were derived from Benson and Gensmer (1986).

Table 13. Harvest management effect on forage and root dry matter (DM) and N yields of Nitro alfalfa. [1]

Harvest management [2]	Forage yield [3] (tons DM/acre)			Root yield (tons DM/acre)	Fall N Yields (lbs N/acre)	
	Summer	Fall	Total		Root	Root+Forage
H1	—	1.4	1.4	1.1	68	129
H2	2.0	0.7	2.7	1.1	65	106
H3	3.0	0.5	3.5	1.0	53	90
H4	2.5	0.5	3.0	1.0	53	93
LSD (0.05)	0.3	0.1	0.3	0.2	13	13

1. Adapted from Sheaffer et al. (1988a). Values are averaged for Becker, Rosemount, and Waseca, MN. Alfalfa seeded on April 23 (average date). Incorporated herbicide (Balan) applied before seeding.
2. H1 = forage accumulated in situ until fall; H2 = two summer harvests at bud and herbage regrowth harvested at first flower in fall; H3 = three summer harvests at bud and herbage regrowth harvested at bud in fall; H4 = two summer harvests at first flower and herbage regrowth harvested at first flower in fall.
3. Summer forage yields = yields from harvests before early September; Fall forage yield = yields from harvest in October.

MANAGEMENT OF NITRO AND OTHER NONDORMANT VARIETIES

Establishment

Nitro can either be established using a companion crop or solo seeded without a companion crop, using a preplant incorporated herbicide (Sheaffer et al., 1988b). Maximum alfalfa forage dry matter yields and fall root dry matter and N production are achieved by early spring seeding without a companion crop (Table 12). Alfalfa forage yields are less for solo seeding without a herbicide than with a herbicide, but total forage yields (alfalfa + weeds) and returns over costs are greater for solo seeding without a herbicide.

When the risk of soil and wind erosion necessitates a companion crop, early removal of the small grain at the boot stage is recommended to maximize alfalfa forage and N production. With shallow seeding into a firm seedbed, 10 to 12 lbs/acre of Nitro seed is sufficient to produce maximum forage dry matter and N yields.

Harvest management

For the optimum production of harvested forage and N for incorporation, Nitro requires judicious harvest management (Sheaffer *et al.*, 1988a). Nondormant alfalfas like Nitro flower about one week earlier than adapted dormant varieties. Nondormants also lose quality sooner than more dormant varieties because they are more susceptible to the leaf loss caused by foliar disease if harvesting is delayed until first flower. Nitro has undergone selection for leaf disease resistance (Table 6) and does have more resistance to leaf disease than most nondormants (Table 11), but it is still less resistant than many of the currently available dormant varieties.

The highest yields of quality forage occur when Nitro is harvested three or four times at the bud stage in the year of establishment (Harvest management H3, Tables 13 and 14). In southern Minnesota, if alfalfa is seeded in late April, three harvests at bud can be taken by early September. At more northern latitudes only one or two harvests may be possible before early September.

Fall harvest management influences the quantity of BNF-derived N available for incorporation. Harvest and removal of forage in the fall will increase the total season yield, but will also reduce the quantity of N available for incorporation as green manure (Table 13). To allow fall herbage regrowth for incorporation, the final summer forage harvest should occur in early September.

The harvest system which currently is the most economical for production of Nitro consists of frequent harvest during summer of the seeding

Table 14. Harvest management effect on summer and total season (summer and fall) forage crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and relative feed value (RFV) of Nitro alfalfa.[1]

Harvest management [2]	Summer (percent)			Summer RFV [3]	Total Season [4] (percent)			Total Season RFV
	CP	NDF	ADF		CP	NDF	ADF	
H1	—	—	—	—	11.7	69.7	56.1	59
H2	20.1	42.6	33.9	125	19.1	46.4	36.6	114
H3	19.9	43.5	35.1	121	20.5	43.5	34.7	122
H4	17.4	47.0	38.6	112	18.8	45.5	37.0	116
LSD (0.05)	0.7	1.2	1.2	4	1.0	1.7	2.0	5

1. Adapted from Sheaffer *et al.* (1988a). Values are averaged for Becker, Rosemount, and Waseca, MN locations.
2. Harvest management: H1 = Herbage accumulated in situ until fall harvest; H2 = two summer harvests at bud and herbage regrowth harvested at first flower in fall; H3 = three summer harvests at bud and herbage regrowth harvested at bud in fall; H4 = two summer harvests at first flower and herbage regrowth harvested at first flower in fall.
3. RFV (relative feed value) based on concentration of CP, ADF and NDF.
4. Includes forage quality from summer and fall forage.

year and again in the fall at about the time of the first killing frost; only roots and crowns are incorporated (Harvest management H3, and Production system N1; Table 15).

When alfalfa forage is assigned a cash market value based on CP and TDN content, and N contribution is valued based on current N fertilizer prices, a greater value is placed on fall herbage production for use as forage than as a source of N. However, the incorporation of herbage in the fall may appeal to those producers desiring to reduce cash costs for the purchase of N fertilizers, or those practicing organic farming.

While herbage incorporation may be currently uneconomical in the short-term, based on current N prices, growers need to monitor cropping system economics because this practice may have the most favorable long-term effect on conserving energy and sustaining soil resources.

Tillage

Tillage method has not consistently affected the recovery of residual N from alfalfa. Levin et al. (1987) compared the corn response to added N following conventional (moldboard plowing) and no-till seeding into alfalfa residue. Although greater N mineralization was expected with the conventional system, no difference in corn N uptake or response to applied N was found.

Time of tillage has also had inconsistent effects on N recovery following alfalfa. For a loam soil, Harris and Hesterman (1987) found that spring plowing resulted in greater recovery of incorporated alfalfa N by corn than did fall plowing. In contrast, alfalfa N recovery for the two tillage methods did not differ on a sandy loam. Groya and Sheaffer (1985) found no consistent differences between fall and spring conventional moldboard tillage on N uptake or yield of sudangrass (*Sorghum bicolor* L. Moench) following alfalfa.

Table 15. Returns over cash costs for alfalfa harvest managements and two alfalfa production systems. [1]

Production system [2]	Harvest management [3] ($/acre) H1	H2	H3	H4
N1	–57 [4]	97	177	147
N2	–92	57	138	89

1. Adapted from Sheaffer *et al.* (1988a).
2. Production system: N1 = Summer and/or fall herbage harvested; crowns and roots incorporated. N2 = Summer herbage harvested for harvest managements (H2, H3, and H4), fall herbage regrowth, or summer (H1) crowns and roots incorporated.
3. H1 = Herbage stockpiled in situ till fall; H2 = two summer harvests at bud and herbage regrowth harvested in fall; H3 = three summer harvests at bud and herbage regrowth harvested in fall; H4 = two summer harvests at first flower and herbage regrowth harvested in fall.
4. Revenue values were derived from the cash market value of alfalfa and from the fertilizer N replacement value of alfalfa available for incorporation in the fall. Alfalfa was assigned a cash value based on its relative feed value (RFV) compared to that of a reference forage with RFV = 100 (CP, ADF, and NDF of 12%, 41%, and 53%). The cash value of the reference forage was based on the content of CP and total digestible nutrients [TDN = 96.35 – (ADF % x 1.15)]. An opportunity cost was established at which the same nutrients could be obtained by purchasing soybean meal for CP and corn for TDN. Corn was valued at $0.04/lb and soybean meal at $0.06/lb based on five-year average prices. Alfalfa herbage and root N available for incorporation and fertilizer N replacement was valued based on the five-year average price of anhydrous ammonia (0.15/lb). The fertilizer N replacement value was calculated based on total reduced N in the root and herbage without distinguishing between N derived from the soil or symbiosis.

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