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ANNUAL MEDICS AND BERSEEM CLOVER AS EMERGENCY
FORAGES OR GREEN MANURE FOR CANOLA

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Anil Shrestha

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**ANNUAL MEDICS AND BERSEEM CLOVER AS EMERGENCY FORAGES OR
GREEN MANURE FOR CANOLA**

By

Anil Shrestha

A DISSERTATION

**Submitted to
Michigan State University
in partial fulfillment of the requirements
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ABSTRACT

ANNUAL MEDICS AND BERSEEM CLOVER AS AN EMERGENCY FORAGE OR GREEN MANURE FOR CANOLA

By

Anil Shrestha

Development of cropping systems which provide quality emergency forages and reduce the need for chemical fertilizer nitrogen (N) in a subsequent non-legume crop may benefit farmers. This study evaluated the forage dry matter (DM) yield and quality of three annual medic species [barrel medic (*Medicago truncatula* Gaertn. 'Mogul'), burr medic (*M. polymorpha* L. 'Santiago'), and snail medic (*M. scutellata* L. 'Sava')], and berseem clover (*Trifolium alexandrinum* L.); quantified N accumulated at plowdown by these species; evaluated N fertilizer replacement value (FRV) of legumes on a subsequent canola (*Brassica napus* L.) crop; and compared the response of canola to fertilizer N under various cropping systems.

The annual medics, berseem clover, alfalfa (*M. sativa* L.), and spring canola were seeded in early May. All the alfalfa, spring canola, and some annual medic and berseem clover plots were harvested at 60 days after planting (DAP), while some of the annual medic and berseem clover plots were grown as green manure for 90 days. All plots were moldboard plowed 90 DAP and winter canola 'Ceres' was planted in mid-August. Plots were split into 4 sub-plots and fertilizer N was applied in March at rates of 0, 50, 100, and 150 kg N ha⁻¹.

Annual medics and berseem clover produced similar or higher yields than did alfalfa when harvested at 60 DAP. Annual medic regrowth (except Mogul) was less

than regrowth of alfalfa or berseem clover and contained mostly residue and seed pods. The medics generally had similar crude protein but higher acid detergent and neutral detergent fiber concentrations than did alfalfa at 60 DAP. Berseem clover produced DM yield and forage quality comparable to alfalfa at 60 DAP and 90 DAP.

Legumes had little effect on yield of the subsequent canola. Canola responded to added levels of fertilizer N and no interactions were observed between the cropping system and N treatments. Harvesting the legume at 60 DAP and plowing down the regrowth at 90 DAP or plowing down the unharvested legume at 90 DAP produced similar canola grain yields. The amount of above-ground biomass or N content at plowdown was not significantly correlated with canola yield. Fertilizer replacement value of legumes were non-estimable due to lack of significant differences in the yield of canola following a non-legume or a legume at the 0 N level. Among the annual legumes tested, berseem clover has the most potential as an emergency forage.

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PREFACE

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Chapter 1

YIELD AND QUALITY OF ANNUAL MEDICS AND BERSEEM CLOVER AS EMERGENCY FORAGES.

ABSTRACT

Severe winter-kill of alfalfa (*Medicago sativa* L.) in some years prompts the need for emergency forages in northern locations. Our primary objective was to evaluate the forage dry matter (DM) yield and quality of three annual medic species, [barrel medic (*M. truncatula* Gaertn. cv. Mogul), burr medic (*M. polymorpha* L. cv. Santiago), and snail medic (*M. scutellata* L. cv. Sava)], and berseem clover (*Trifolium alexandrinum* L.) as emergency forages compared to alfalfa. Field experiments were conducted in 1994 at two locations on a Capac loam (fine-loamy, mixed, mesic Aeric Ochraqualfs) and Kalamazoo loam (fine-loamy, mixed, mesic Typic Hapludalf). The experiments were repeated in 1995. Plots were seeded in early May and harvested 60 days after planting (DAP). Dry matter (DM) yields, crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) were determined. Dry matter yield and forage quality of the regrowth 30 days after the first harvest were also determined. Annual medics and berseem clover produced similar or higher yields than alfalfa in the seeding year in 1995 at one location and in 1996 at another location at first harvest. Annual medic regrowth (except Mogul) was less than either alfalfa or berseem clover regrowth and medic biomass contained mostly residue and seed pods. The highest

total seasonal average DM yield was obtained from Mogul (4.6 Mg ha⁻¹). Berseem clover produced an average DM yield of 2.2 Mg ha⁻¹ at first harvest and 1.8 Mg ha⁻¹ at second harvest across the 2 locations with average CP, ADF, and NDF concentrations of 200, 279, and 395 g kg⁻¹, respectively, at first harvest and 191, 217, and 333 g kg⁻¹, respectively, at second harvest. Annual medics had variable forage quality across locations and years. Crude protein concentration of annual medics ranged from 144 to 187 g kg⁻¹ and the ADF and NDF concentrations ranged from 276 to 355 g kg⁻¹ and 361 to 470 g kg⁻¹ respectively, at first harvest. The average CP, ADF, and NDF concentration of Mogul at second harvest was 174, 239, and 342 g kg⁻¹, respectively. Annual medics can be used as emergency forage if only one harvest is desired. Berseem clover has potential as an emergency forage. It can produce DM yield and forage quality comparable to alfalfa in the seeding year and can be harvested twice during the season.

INTRODUCTION

Severe winter-kill of alfalfa (*Medicago sativa* L.) in some years prompts the need for emergency forages in northern locations. Sorghum-sudan grass is commonly used as an emergency forage in Michigan but its success is limited due to soil moisture conditions at the time of seeding (Leep, 1996). Sorghum-sudan grass is also generally lower in crude protein concentration than forage legumes (Hesterman, et al., 1991). Small grain or small grain/pea mixture has been recommended as an emergency forage because it allows summer seeding of alfalfa in the same field after the small grain or small grain/pea mixture is harvested in late June or July (Leep, 1996). Annual legumes may benefit farmers because they can provide high protein animal feed as well as fix atmospheric nitrogen in the soil for the next crop.

Potentials for using annual medics (*Medicago* sp.) and berseem clover (*Trifolium alexandrinum* L.) as forages have not been explored in Michigan. Annual medics are legumes closely related to alfalfa. They are self-pollinating true annuals which flower, set seed and die within one growing season (Bauchan and Sheaffer, 1994). They are native to the Mediterranean region but now occur in the major continents of the world and the most widespread species is *M. polymorpha* and *M. minima* (Crawford, 1985). Lesins and Lesins (1979) recognized only 35 species, whereas Crawford et al.(1989) recognized 82 species of annual medics. Annual medics are used as winter annuals in Australia. If planted in spring in a northern temperate climate they can be grown as summer annuals. They are not known to be

cold hardy and are generally susceptible to frost. Most of the medics complete their life cycle in 65 to 100 days after planting (Bauchan and Sheaffer, 1994).

There is an increasing interest in the use of annual medics in sustainable agriculture systems. However, the U. S. collection of annual medic germplasm is underutilized because of lack of agronomic information (Diwan et al., 1994). The use of annual medics as cover crops is being explored in several states in the US. Studies are being conducted on their ability to fix biological nitrogen, increase organic matter, reduce soil erosion, and in pest and weed management. Medics have been found to be best adapted to soils with a pH of 6 or above. They have been used as a hay crop, but are difficult to cut and bale, so grazing is a more suitable alternative. When grazed high, they have been found to regrow. Annual medics have forage quality potential similar to alfalfa and can cause bloat (Bauchan et al., 1994). Some species of annual medics have been reported to produce average dry matter (DM) yields of 4.1 to 5.7 Mg ha⁻¹ when seeded in early May and harvested 70 days later (Sheaffer and Barnes, 1994). Dry matter yields, percent ground cover, senescence characteristics, seeding characteristics, and forage quality of fourteen cultivars representing five annual *Medicago* species have been studied in Indiana. Dry matter yields ranged from 1 to almost 9 Mg ha⁻¹ in a single cutting, with crude protein values of 14.9 to 17.6 % of dry weight (Johnson et al., 1993). Annual medics have also been used as reseeding pasture legumes in northern Utah. Among the species tested, black medic (*Medicago lupulina* L.) was shown to be better adapted to the local environment (Rumbaugh and Johnson, 1986). Similarly, some species of annual medics were also seeded as pasture

legumes in Arizona. Rapidly maturing medics could be established under conditions of less than 100 mm precipitation (Brahim and Smith, 1993).

Medics are generally not native to areas that receive significant summer precipitation. They provide high quality forage in many regions with Mediterranean climate and they are used on approximately 50 million hectares in Australia in pastures as a rotation crop (Crawford et al., 1989). Most medic species are winter annuals adapted to Mediterranean climates. In colder temperate climates they are best used as summer annuals (Rumbaugh and Johnson, 1986). Medics have been found to establish best in paddocks in which previous weed control has been excellent. This may require seeding after one or more cereal crops (Ewing, 1984). Clarkson et al., (1987) reported 8 to 10 Mg ha⁻¹ DM yields for medics in pastures in Queensland, Australia.

Berseem clover is an erect, cool-season annual legume which is believed to have originated in the region of Egypt and Syria (Baldrige et al., 1992). It is commonly called *Egyptian* clover because it is an important crop in Egypt (Knight, 1985a). Berseem was introduced in the United States in 1896 and was first grown successfully in California in 1918 (Kretschmer, 1964). Since then, it has been grown successfully in Washington, Oregon, California, Arizona, and some parts of Florida (Knight, 1985b). The regions in which the minimum temperatures are greater than -6° C have been reported suitable for growing berseem clover as a winter annual in the USA. Its greatest potential is as a green-chopped forage or pasture and it is known to be non-bloating (Dennis and Massengale, 1962). Dry matter yields ranging from 7.4 to 10 Mg ha⁻¹ from two to three harvests have been reported from Montana (Baldrige

et al., 1992). Similarly, DM yield of 4.5 Mg ha⁻¹ of berseem with 19.5% crude protein (CP), 27% acid detergent fiber (ADF), and 67.4% total digestible nutrients (TDN) was reported from Oregon (Saunders et al., 1990). Experiments in California found DM yields of 16 Mg ha⁻¹ in six harvests with CP averages of 22% over all harvests (Williams et al., 1990). It has been recommended in Iowa that the first cutting from spring planted berseem clover be taken in early June and the next cutting 45 to 50 days later (Hofstetter, 1994). Dry matter yields of 10.7 Mg ha⁻¹ were found under different management systems in Montana in which berseem clover responded better to systems with longer harvest intervals (Westcott et al., 1995).

Berseem is a popular forage crop in other parts of the world such as the Mediterranean region, Near East, and India (Kretschmer, 1964). It is known to be one of the most productive and nutritive winter forage crops in sub-tropical regions (Singh, 1993). It is also known to grow in regions such as the semiarid regions of Israel, where a DM yield of 10 Mg ha⁻¹ was reported (Kishinevsky et al., 1992).

Forage quality is an important factor in the evaluation of forages as an emergency feed. Nutritive concentration, digestibility, intake and efficiency of utilization are often considered essential components of high quality forage. Fiber analysis is commonly performed on forage samples to estimate nutritive value (Van Soest and Mertens, 1984). Neutral detergent fiber (NDF) is negatively associated with forage quality, while crude protein (CP) represents one of the primary nutrients in most balanced livestock rations (Fick and Mueller, 1989).

The objectives of this study were: (i) to determine the forage DM yields of 3 species of annual medic and berseem clover; (ii) to determine the forage quality of these species; and (iii) to evaluate their use as emergency forages in comparison with 'Nitro' alfalfa in the establishment year.

MATERIALS AND METHODS

Experiments were conducted in 1994 and 1995 at two sites in Michigan: Michigan State University Agronomy Farm, East Lansing on a Capac loam (fine-loamy, mixed, mesic Aeric Ochraqualfs) and on a Kalamazoo loam (fine-loamy, mixed, mesic Typic Hapludalf) at the Kellogg Biological Station (KBS), Hickory Corners. Climatological data for 1994 and 1995 are shown in Table 1. In both years, P and K were applied to maintain soil test levels at or above those recommended for alfalfa production. The soil test data for the two years and two locations are summarized in Table 2. Seed bed preparation included conventional tillage and cultipacking.

First year: 1994

Main plots of 24.3 by 1.8 m at KBS and 24.3 by 2 m plots at East Lansing were arranged in a randomized complete block design with four replications. Barrel medic 'Mogul', burr medic 'Santiago', Snail medic 'Sava', and 'Nitro' alfalfa seeds were inoculated with *Rhizobium meliloti* while berseem clover seeds were inoculated with *R. trifolii* and seeded with a small grain drill and cultipacked. The three annual medic species were chosen to represent three different growth habits, Mogul a semi-erect, Santiago a prostrate, and Sava an erect growing medic. Seeding rates of the legumes are listed in Table 3. Determination of seeding rates were based on approximately 270 pure live seeds (PLS) m⁻². Planting, irrigation, and harvest dates are summarized in Table 4.

A preplant application of Eptam (*s*-ethyl dipropylthiocarbamate) at 3.3 kg ha⁻¹ a.i. was incorporated at each location. Total water applied to all plots was 5 cm. Legume yields were measured by cutting 0.9 X 6.1 m strips within each plot to a stubble height of 5 cm by a flail mower. The first cut was taken approximately 60 days after planting (DAP). Wet forage yield for each plot was adjusted to dry weight by taking subsamples and drying them in a forced-air oven at 60°C for 72 hours. Subsamples of approximately 800 g were hand clipped and oven-dried at the same temperature and for the same duration, ground to pass a 2-mm screen and then through a 1-mm screen in a cyclone mill (Wiley Corporation) and saved for forage quality analysis. All plant samples were subjected to the Hach procedure for total N determination (Hach et al., 1985). The forage CP concentration was estimated by multiplying total N by 6.25. ADF and NDF concentrations in the samples were determined by the procedure of Goering and Van Soest (1970). One ml alpha-amylase was added to each sample in order to digest starch before extracting NDF.

Estimates of forage yield for a second cut were made approximately 30 days after the first cut by taking 0.25 m² quadrat measurements. The samples included stems, leaves, residue, and seed pods of the medics. Wet forage yield adjustments were made by the same procedure as described earlier.

Second year: 1995

The experiments were repeated in 1995 in different plots at the same locations. Details of the plots are summarized in Table 2. Similar planting practices were used as in 1994. The same *Rhizobium* inoculation was used for alfalfa and berseem as in

1994 but the annual medics were inoculated with a 1:1 mixture of *R. meliloti* and *Rhizobium* special number 1 (Nitragin, Liphatech Inc.). Planting, irrigation, and harvest dates are summarized in Table 3. Harvesting, yield estimation, subsampling, grinding, and forage quality determination methods were similar to those described for 1994.

Statistics

Analysis of variance was performed on the data for DM yield, CP, ADF, and NDF concentration within each location and significant species X location interactions were identified. Significant differences among species were determined with an *F*-test and mean separation was done by using Fisher's LSD values where the *F*-test denoted significance ($P \leq 0.05$). All analyses were performed utilizing GLM of SAS Statistical Package version 6.0.3 (SAS Institute, 1988).

RESULTS AND DISCUSSION

Forage DM yields

Year effects were detected for first harvest DM yield in one out of the two years in both locations (Table 5). This suggests that annual medics and berseem clover can produce as much or more biomass than alfalfa in the seeding year at 60 DAP under favorable conditions. Among the differences observed, Mogul performed significantly better than the other species in terms of forage biomass production at KBS in 1994. Sava and berseem clover were similar in DM yields to alfalfa, while Santiago yielded significantly lower than the other species. Sava yielded significantly higher than the other medics and alfalfa at East Lansing in 1995. Dry matter yields of all species at 60 DAP was greater in 1994 than 1995 in East Lansing. This could be due to lower precipitation in 1995 than in 1994 (Table 1). In contrast, DM yields across species were generally greater in 1995 than in 1994 at KBS. Some of the difference in DM yield at KBS can be attributed to seasonal variation between the two years (irrigation was required at KBS only in 1994).

Even though all species appeared similar in forage DM yields, Santiago grew very close to the ground and did not appear suitable for harvesting as hay. Mogul, Sava, and berseem grew more erect and appeared suitable to mechanical harvest. Sava senesced and contained many seed pods at 60 DAP while Mogul and berseem remained vegetative with few seed pods. This indicates that Sava should be harvested a few days earlier if vegetative forage is desired.

Estimates of forage biomass 30 days after first harvest showed that significant differences were present in the regrowth of the species in both years (Table 5).

Regrowth of Sava was lowest of all species in both years. Santiago was intermediate and regrowth of both Mogul and berseem was greater than the other species. The DM yield of the regrowth of Mogul and berseem was similar to alfalfa and significantly higher than that of the other medic species at KBS in 1995. At East Lansing, DM yield of Mogul, berseem, and alfalfa was similar at second harvest in both 1994 and 1995. However, the regrowth of Mogul at both locations and both years was decumbent and not suited to mechanical harvesting. Whereas, the regrowth of berseem was more erect and suited to mechanical harvesting. The biomass of Sava at second harvest consisted mostly of residue and seed pods in both years. The regrowth of Santiago also contained a lot of seed pods and had very little green, vegetative structures.

Total seasonal DM yields among species were not significantly different at East Lansing in 1994. Whereas, in 1995, total seasonal yield of Mogul, berseem, and alfalfa were similar and significantly higher than the total seasonal yield of Santiago and Sava at East Lansing. Likewise, total seasonal DM yield of Mogul, berseem, and alfalfa was similar and significantly higher than that of Santiago and Sava at KBS in 1994 and 1995. Among the annual medics tested, only Mogul appeared suitable for two harvests. However, the second harvest was not suitable for mechanical harvest due to the decumbent regrowth. Berseem clover may have good potential as either hay or fresh green chop in both harvests.

Forage quality

A significant species X location interaction occurred in both years for forage quality parameters. Hence, these parameters were analyzed separately for each location. Crude protein concentration of berseem was highest among all the species at first harvest in both years at East Lansing. Whereas, crude protein concentration of berseem was similar to alfalfa and significantly higher than the other species in 1994 and significantly higher than all other species except Mogul in 1995 (Table 5). Santiago and Sava had the lowest CP concentrations at East Lansing in 1994, Santiago was similar in CP concentration to the other species in 1995. Alfalfa had significantly lower ADF and NDF concentrations in both years at East Lansing. Berseem had similar ADF and NDF concentrations as Mogul and Santiago in 1994 but significantly lower than these species in 1995.

At KBS, berseem had the highest CP concentration at 60 DAP in 1994 but was lower than Mogul, Santiago, and alfalfa in 1995. Santiago and Sava had the lowest CP concentrations in 1994. As in East Lansing, the ADF and NDF concentration of alfalfa was lowest at KBS in both years. In both years Sava had the highest ADF and NDF values. Berseem and Mogul were intermediate between alfalfa and Sava in ADF and NDF concentrations in both years at KBS. Santiago was similar to Sava in ADF and NDF concentration in 1994, but had lower concentrations of these quality parameters than Sava in 1995.

Crude protein concentrations at second harvest showed that alfalfa and berseem clover had significantly higher CP concentrations than the other species at second

harvest at East Lansing in 1994 (Table 5). However, in 1995 the CP concentrations of all the species were similar at second harvest at East Lansing. Berseem clover generally had a significantly lower ADF and NDF concentrations than the annual medics. Santiago and Sava generally had similar ADF and NDF concentrations at second harvest. Among the annual medics, Mogul had the lowest concentration of ADF and NDF at second harvest. Differences in forage quality were also observed at KBS at second harvest. Berseem, alfalfa, and Mogul generally had significantly higher CP concentrations than Santiago and Sava. The ADF and NDF concentrations of all species at second harvest varied a great deal from one year to the other. Alfalfa and berseem clover generally had lower ADF and NDF concentrations than the annual medics in 1994. However, the ADF and NDF concentrations of alfalfa and berseem were generally higher than the annual medics in 1995. But, compared to annual medics, alfalfa and berseem clover may be more palatable forages as they were more vegetative and contained very little desiccated structures and seed pods at second harvest.

SUMMARY

In one year out of the two, annual medics and berseem clover produced DM yields similar to alfalfa in the seeding year when harvested 60 DAP. In the other year, Mogul produced significantly higher DM yield than alfalfa at East Lansing and Sava produced significantly higher DM yield than alfalfa at KBS. Among the annual medics, the highest total season DM yield was produced by Mogul. Regrowth of annual medics Sava and Santiago was poor in comparison to alfalfa, berseem, and Mogul and the biomass contained mostly residue and seed pods. Although regrowth of Mogul was greater, it appeared more suited to grazing than mechanical harvesting due to its lower growth habit. Berseem clover grew more erect and appeared more suited to mechanical harvesting in comparison to the annual medics. In addition, berseem clover had forage quality comparable to alfalfa. Annual medics were variable in CP, ADF, and NDF concentrations across locations and years. They were comparable to alfalfa in CP but were generally higher in ADF and NDF concentrations. Mogul was generally higher in CP and lower in ADF and NDF concentrations than the other annual medics. Annual medics, specially Mogul, can be used as an emergency forage legume in Michigan if only one harvest is desired. Berseem clover has good potential as an emergency forage legume as it can produce good yields and high quality forage and can be harvested at least twice during the growing season.

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Table 1. Climatological data from May 1994 to August 1994 and May 1995 to August 1995 at East Lansing and Kellogg Biological Station (KBS), Michigan.

Year and Location	Month	Total Precipitation	Mean Temperature
		mm	°C
1994			
East Lansing	May	46.2	12.7
	June	185.9	19.8
	July	121.2	20.9
	August	143.3	18.6
KBS	May	4.0	15.8
	June	174.4	21.5
	July	160.2	22.4
	August	119.5	21.9
1995			
East Lansing	May	63.5	12.6
	June	42.2	19.8
	July	100.6	21.4
	August	116.1	23.2
KBS	May	72.7	14.8
	June	92.2	21.6
	July	82.9	24.4
	August	110.4	24.8

Table 2. Initial soil test values at East Lansing and KBS in 1994 and 1995.

Year and Location	Soil pH	Avail. P	Exch. K
1994		----- kg ha ⁻¹ -----	
East Lansing	7.6	82	228
KBS	7.3	80	130
1995			
East Lansing	7.3	82	159
KBS	7.6	74	226

Table 3. Seeding rate of legumes at East Lansing and KBS in 1994 and 1995.

Species	Seeding rate
	kg ha ⁻¹
'Nitro' Alfalfa	25
'Mogul' Barrel medic	15
'Santiago' Burr medic	15
'Sava' Snail medic	32
Berseem clover	12

Table 4. Legume planting, irrigation, and harvest dates at East Lansing and KBS in 1994 and 1995.

Year & Location	Planting	Irrigation	Harvest 1	Harvest 2
1994				
East Lansing	13 May	25 May	18 July	8 August
KBS	6 May	30 May	11 July	9 August
1995				
East Lansing	12 May	21 May	17 July	14 August
KBS	8 May	-	13 July	10 August

Table 5. Average dry matter (DM) yield, crude protein (CP), acid-detergent fiber (ADF), and neutral-detergent fiber (NDF) of legume species at harvest 1 (60 days after planting) and harvest 2 (90 days after planting) in 1994 and 1995 at East Lansing and Kellogg Biological Station (KBS), Michigan.

Year, Location, and Species	DM Yield			Harvest 1			Harvest 2		
	Harv.1	Harv.2	Total	CP	ADF	NDF	CP	ADF	NDF
	----- Mg ha ⁻¹ -----			----- g kg ⁻¹ -----					
1994									
East Lansing									
‘Nitro’ alfalfa	2.1	1.6	3.7	218	255	326	187	183	299
‘Mogul’ medic	3.6	1.4	5.0	170	304	374	142	246	347
‘Santiago’ medic	3.1	1.1	4.2	111	307	382	139	275	350
‘Sava’ medic	3.2	0.6	3.8	151	360	449	131	279	367
Berseem clover	2.7	1.6	4.3	233	280	371	217	180	292
LSD (0.05)	NS	NS	NS	32	37	42	34	47	48
KBS									
‘Nitro’ alfalfa	1.8	1.3	3.1	174	211	380	205	200	293
‘Mogul’ medic	2.8	2.6	5.4	186	259	366	174	227	294
‘Santiago’ medic	0.8	1.1	1.9	152	334	461	130	220	300
‘Sava’ medic	1.4	1.1	2.5	168	328	481	146	274	378
Berseem clover	1.2	2.1	3.3	212	257	417	196	197	289
LSD (0.05)	0.7	0.7	0.8	36	28	36	34	27	28
1995									
East Lansing									
‘Nitro’ alfalfa	1.2	1.9	3.1	170	217	359	186	191	299
‘Mogul’ medic	1.3	2.0	3.3	185	223	321	175	220	339
‘Santiago’ medic	1.2	1.1	2.3	180	319	419	177	241	395
‘Sava’ medic	2.2	0.0=	2.2	158	351	452	145	325	435
Berseem clover	1.7	2.1	3.8	178	263	369	178	245	403
LSD (0.05)	0.5	0.7	0.7	19	17	16	NS	10	14
KBS									
‘Nitro’ alfalfa	3.1	1.6	4.7	195	259	383	164	232	372
‘Mogul’ medic	2.9	1.8	4.7	210	318	385	204	264	391
‘Santiago’ medic	2.9	0.7	3.6	205	335	431	110	226	300
‘Sava’ medic	2.2	0.0=	2.3	158	375	498	141	196	302
Berseem clover	3.2	1.6	4.8	178	316	423	175	247	351
LSD (0.05)	NS	0.8	1.1	14	19	27	25	23	79

= DM yield present only in traces.

Chapter 2

YIELD POTENTIAL OF ANNUAL MEDIC AND BERSEEM CLOVER UNDER DIFFERENT SYSTEMS OF HARVEST MANAGEMENT

ABSTRACT

Annual medics and berseem clover have been suggested as emergency forages in northern locations. However, yield potential of these legumes under different systems of harvest management has not been evaluated. Our objective was to determine forage dry matter (DM) yields of barrel medic (*Medicago truncatula* Gaertn. cv. Mogul) and berseem clover (*Trifolium alexandrinum* L.) under different harvest management systems, compare the DM yields with alfalfa (*M. sativa* L.) and red clover (*Trifolium pratense* L.), and evaluate their over-wintering capability. A field experiment was conducted in 1995 on a Capac loam (fine-loamy, mixed, mesic Aeric Ochraqualfs). The species were seeded in early May and harvested under two systems of management. In the first system, the first harvest was taken 60 days after planting (DAP) followed by a second harvest 45 days later. In the second system, the first harvest was taken 75 DAP followed by a second harvest 45 days later. Berseem clover produced the highest total seasonal DM yield under both systems of management (4.5 Mg ha⁻¹). The DM yields of all species were similar at first harvest in the 60-day system, but barrel medic yield was lower than that of the other species at first harvest in the 75-day system. Barrel medic regrowth was very low in comparison to the other species and less suited to mechanical harvesting under both harvest

management systems. Berseem clover regrowth was more erect than regrowth of barrel medic and was suitable for mechanical harvest. Barrel medic and berseem clover winter-killed and did not re-seed, whereas good stands of alfalfa and red clover were obtained in the following season with a DM yield of 5.1 and 11.5 Mg ha⁻¹ respectively. Berseem clover may be better than barrel medic in terms of biomass production as an emergency forage legume and can be grown successfully if the objective of the producer is not to replant alfalfa in the same field as winter-killed alfalfa. However, very little or no regrowth of berseem clover can be expected the following spring.

INTRODUCTION

Annual medics (*Medicago* sp.) and berseem clover (*Trifolium alexandrinum* L.) have been suggested as emergency forages in northern locations (Shrestha et al., 1995). However, yield potential of these legumes under different systems of harvest management must be determined for maximizing forage production. Among the various annual legume species studied, barrel medic (*Medicago truncatula* Gaertn. cv. Mogul) and berseem clover appeared most promising in terms of dry matter (DM) production and forage quality in Michigan (Shrestha and Hesterman, 1995). The annual legumes in these studies were planted in early May and harvested 60 days after planting (DAP) followed by a second harvest 30 days later. Substantial regrowth of Mogul and berseem occurred after the first cut. Shrestha and Hesterman (1995) reported crude protein (CP) concentrations of Mogul and berseem in the range of 170-210 g kg⁻¹ and 178-233 g kg⁻¹, respectively, at 60 DAP in studies conducted at East Lansing and Kellogg Biological (KBS), Michigan. The acid detergent fiber (ADF) and neutral detergent fiber (NDF) concentration of Mogul ranged from 223-318 g kg⁻¹ and 321-385 g kg⁻¹, respectively. Similarly, the ADF and NDF content of berseem ranged from 257-316 g kg⁻¹ and 369-423 g kg⁻¹, respectively.

For barrel medic and berseem clover to be a viable emergency forage legume, its performance and production must be evaluated under different systems of cutting management. The affect of cutting time on their productivity must be estimated. Their performance must also be compared with the dominant forage legumes of the

region, viz. alfalfa (*Medicago sativa* L.) and red clover (*Trifolium pratense* L.) in order to justify it as an alternative to replanting alfalfa or red clover.

Mogul medic has a semi-erect growth habit, and is difficult to cut and bale as a hay crop (Baucham et al., 1994). In contrast, berseem clover is an erect, cool-season annual legume (Kretschmer, 1984). Berseem has been grown successfully in California, Washington, Oregon, Arizona, and some parts of Florida (Knight, 1985). It is known to be non-bloating and has been used as a green-chopped forage or pasture legume (Dennis and Massangale, 1962). Baldrige et al. (1992) reported DM yields of 7.4 to 10 Mg ha⁻¹ from two to three cuts in Montana. Saunders et al. (1990) reported DM yield of 4.5 to 10 Mg ha⁻¹ in Oregon. Berseem clover is not a new crop in the United States, whereas, barrel medic is relatively new and its use as a forage is still under investigation.

The objectives of this study were: (i) to determine forage DM yields of barrel medic and berseem clover under different harvest management systems, (ii) to compare the DM yields of barrel medic and berseem clover with alfalfa and red clover, and (iii) to evaluate the over-wintering capacity of barrel medic and berseem clover.

MATERIALS AND METHODS

An experiment was conducted in 1995 at the Michigan State University Agronomy Farm, East Lansing on a Capac loam (fine-loamy, mixed, mesic Aeric Ochraqualf). Soil samples were taken and phosphorus and potash were applied to maintain soil test levels at or above that recommended for alfalfa production. Main plots of 12.2 X 2.1 m were arranged in a randomized complete block design with four replications. Barrel medic (Mogul), berseem clover, alfalfa cv. Pioneer 5262, and medium red clover were inoculated with a host specific *Rhizobium* sp. and seeded on May 12, 1995 with a row planter. Seeding rates are shown in Table 1. A preplant incorporation of Eptam (*S*-ethyl dipropylcarbamothiate) @ 3.3 kg ha⁻¹ a.i. was done. Plots were irrigated on June 21 with a total water application of 5 cm and sprayed on June 23 with 2,4 D-B [4-(2,4-Dichlorophenoxy) butyric acid, dimethylamine salt] @ 1 kg ha⁻¹ a.i. for weed control.

The plots were split for harvest dates. Two harvest systems were imposed: (i) a 60-day system; the first cut was taken 60 DAP followed by a second cut approximately 45 days later and (ii) a 75-day system; the first cut was taken 75 DAP followed by a second cut 45 days later. Planting and cutting schedules are shown in Table 1. Legume yields were measured by cutting 6 X 0.9 m⁻¹ strips within each plot to a stubble height of 5 cm with a flail mower. Plots were left over winter and estimates of DM yields the following spring were taken on June 27 by hand clipping 0.25 m² areas. Wet forage yield for each plot was adjusted to dry weight by taking

about 500 g subsamples and drying them in a forced-air oven at 60° C for 72 hours. Analysis of variance was performed on the data and significant differences between species were determined with an *F*-test. Mean separation was done by using Fisher's LSD where the *F*-test denoted significance ($P \leq 0.05$). All analyses were performed utilizing GLM of SAS Statistical Package version 6.0.3 (SAS Institute, 1988).

RESULTS AND DISCUSSION

There was little difference among species in total seasonal yields under either a 60-day or a 75-day system (Table 2). Barrel medic was outyielded significantly by the other species at all cuts except the first cut under the 60-day system. Alfalfa, berseem clover, and red clover had greater biomass at first harvest under the 75-day system than under the 60-day system. However, barrel medic had similar biomass at first harvest under the 75-day and 60-day system. This suggests that it is better to harvest barrel medic at 60 DAP than 75 DAP as more DM yield was obtained at second cut under the 60-day system (Table 2). Barrel medic grew very close to the ground and was unsuited to mechanical harvesting and appeared more suited to grazing.

Berseem clover produced as much total biomass as did red clover under both the 60-day and 75-day system. Regrowth of berseem was more than that of alfalfa under the 60-day system. Total seasonal yield of berseem clover was significantly higher than that of alfalfa under a 60-day system. Visual observations showed that it may be possible to take a third cut of berseem, which was not done in this study. Total seasonal yield of berseem was identical under a 60-day and 75-day cut system. However, it may be beneficial to take the first cut at 60 DAP if a third cut is desired.

Red clover and alfalfa are popular forage legumes in Michigan and red clover outyielded alfalfa in terms of total seasonal yield under the 60-day system. Observations in Spring of 1996 showed that there was no regrowth of barrel medic or

berseem clover in any of the plots (Table 3). Alfalfa and red clover did regrow and yield estimates taken on July 27, 1996 showed that the average DM yield of alfalfa and red clover was 5.1 and 11.5 Mg ha⁻¹ respectively under both systems of harvest management.

SUMMARY

Barrel medic and berseem clover can be used as an emergency forage in Michigan if the objective of the producer is not to replant alfalfa in the same field as the winter-killed alfalfa. In terms of the growth habit, barrel medic appeared more suited to grazing than mechanical harvesting. It may be better to harvest barrel medic 60 DAP after planting or earlier if substantial regrowth is desired; however, its DM yields are very low. Berseem clover may be a promising annual forage legume as it produced DM yields comparable to red clover and greater than alfalfa in the year of seeding. However, it did not over-winter or re-seed itself the next spring. It may be beneficial to grow berseem clover if an annual emergency forage legume is desired. Earlier studies have reported berseem clover to be comparable in forage quality to alfalfa in the seeding year.

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Table 1. Seeding dates, seeding rates, and harvest schedules of alfalfa, berseem clover, barrel medic, and red clover in 1995.

Species	Seeding date	Seeding rate	60-day system		75-day system	
			1st. cut	2nd. cut	1st. cut	2nd. cut
		kg ha ⁻¹				
Alfalfa	May 12	25	July 18	Aug.31	Aug.1	Sept.15
Berseem	May 12	13	July 18	Aug.31	Aug.1	Sept.15
Barrel medic	May 12	16	July 18	Aug.31	Aug.1	Sept.15
Red clover	May 12	12	July 18	Aug.31	Aug.1	Sept.15

Table 2. Dry matter (DM) yields of alfalfa, berseem clover, barrel medic, and red clover at different dates under the 60-day and 75-day systems of cutting management.

Species	60-day system			75-day system		
	1st. cut	2nd. cut	Total	1st. cut	2nd. cut	Total
	Mg ha ⁻¹					
Alfalfa	1.0	2.5	3.5	1.6	1.9	3.5
Berseem	1.4	3.0	4.4	2.3	2.2	4.5
Barrel medic	1.0	0.8	1.8	1.0	0.4	1.4
Red clover	0.9	3.6	4.5	2.1	2.1	4.2
LSD (0.05)	NS	0.7	0.8	0.8	0.6	1.0

Table 3. Average dry matter (DM) yields of alfalfa, berseem clover, barrel medic, and red clover in the following spring.

Species	DM Yield
	Mg ha ⁻¹
Alfalfa	5.1
Berseem	0.0
Barrel medic	0.0
Red clover	11.5

Chapter 3

ANNUAL MEDICS AND BERSEEM CLOVER AS GREEN MANURE OR ROTATION CROPS FOR CANOLA

ABSTRACT

Cropping systems that reduce the need for chemical fertilizer in canola (*Brassica napus* L.) have been suggested in the Great Lakes region. The objectives of this research were to quantify N accumulated at plowdown by annual medics (*Medicago* sp.) and berseem clover (*Trifolium alexandrinum* L.) managed as a forage or green manure, compare the response of canola to fertilizer N under various cropping systems, and to estimate the N fertilizer replacement values (FRV) of the annual legumes. Field experiments were conducted in 1994/95 and 1995/96 at 2 locations in Michigan on a Capac loam (fine-loamy, mixed, mesic Aeric Ochraqualfs) and Kalamazoo loam (fine-loamy, mixed mesic Typic Hapludalf). Three species of annual medics, [barrel medic (*M. truncatula* Gaertn. cv. Mogul), burr medic (*M. polymorpha* L. cv. Santiago), snail medic (*M. scutellata* L. cv. Sava)], berseem clover, alfalfa (*M. sativa* L. cv. Nitro), and spring canola were seeded in early May. Gamma medic (*M. rugosa* L. cv. Paraponto) was also seeded as an ineffective, non-nodulating control. Some of the barrel medic, burr medic, snail medic, and berseem clover plots were harvested as a forage 60 days after planting (DAP) while some of the plots were allowed to grow as a green manure. Alfalfa, gamma medic, and spring canola plots

were also harvested at 60 DAP. All plots were moldboard plowed 90 DAP and winter canola cv. Ceres was planted in mid-August. Plots were split into 4 sub-plots and fertilizer N applied in March at rates of 0, 50, 100, and 150 kg ha⁻¹. Canola plants winter-killed in 1996 at East Lansing and spring canola was re-planted in mid-May. Winter canola was harvested in July, whereas spring canola was harvested in late August. The effect of annual legume species on yield of the following canola crop was significant at only one location in 1995. Fertilizer N had a significant linear effect on the yield of canola in one year and a quadratic effect in the other year at both locations. There was no interaction between the main treatments and N sub-treatments. Except at one location in 1995, canola grain yield was not significantly different when the preceding legume was harvested at 60 DAP and the regrowth plowed down at 90 DAP or when the entire above-ground biomass was plowed down as green manure at 90 DAP. The amount of above-ground biomass or N at plowdown were not significantly correlated with subsequent canola yield. The soil NO₃ and NH₄ levels measured at 3 different times were similar for all treatments. The FRV of legumes were non-estimable as there was no significant difference between canola following a non-legume or a legume at the 0 N level. Among the annual legumes tested, berseem clover was the most promising species in terms of biomass and N production, and in contribution to the yield of the subsequent canola crop.

INTRODUCTION

Development of cropping systems which reduce chemical fertilizer nitrogen (N) requirements for canola (*Brassica napus* L.) has been suggested in the Great Lakes region. By definition, canola is the seed of *B. napus* L. or *B. rapa* L., the oil component of which contains 20 g kg⁻¹ or less of erucic acid (22:1) and the meal component of which contains 30 μ mol g⁻¹ or less of oil-extracted, air-dried meal of any one or any mixture of the aliphatic glucosinolates, 3-butenyl, 4-pentenyl, 2-hydroxy-3-butenyl and 2-hydroxy-4-pentenyl glucosinolate (Canola Council of Canada, 1990). In other words, canola is a type of rapeseed with low glucosinolates and low erucic acid (Grant and Bailey, 1993). Rape has been grown as a forage crop in the USA since the early 1900's (Karow, 1986). But, the oil of rapeseed was not much used as edible oil due to health concerns over its high levels of erucic acid (Downey, 1976). As an animal feed, the oil-free meal of rapeseed is an excellent source of protein but it contains high levels of glucosinolates which can cause nutritional disorders in animals (Thomas, 1986). Rapeseed oil is also used in producing a variety of polymer and lubricant products and the USA alone uses more than 4.5 million kg of the oil, a large part of which is imported (Auld and Mahler, 1987; Francois, 1994). The health concerns of rapeseed oil led to the development of "double-low" (low erucic acid and low glucosinolate) cultivars of rapeseed known as canola. The term 'canola' is a trademark registered by the Canola Council of Canada and used to differentiate between non-canola rapeseed cultivars and the double-low cultivars (Thomas, 1986;

Francois, 1994). Canola was developed through intensive breeding programs by Canadian scientists. In 1985, the US Food and Drug Administration (FDA) recognized that canola was different from rapeseed and granted canola generally recognized as safe (GRAS) status (Shahidi, 1990). Canola oil is now the world's third largest source of edible oil after soybean (*Glycine max* [L.] Merr.) and palm (*Elaeis oleifera* [HBK] Cortes) oil Nowlin (1991). Estimates from USDA in 1991 show consumption of canola oil in the USA at 0.36 million Mg and canola acreage between 42525 and 56700 hectares (Thompson et al., 1993). Canola has been considered a promising winter cash-crop in the southeast and as a production alternative to winter wheat in the midwestern USA (Porter, 1993; Thompson et al., 1993). Canola was introduced in Michigan in the mid-1980's and since then, there has been an increase the area of canola under cultivation in the upper Great Lakes region of the USA. Canola is known to have relatively high nutrient requirements compared with cereal crops (Grant and Bailey, 1993). Holmes (1980) suggested that oilseed rape has a high requirement for N and needs considerably more than that provided by most soils. Bullock and Sawyer (1991) calculated an optimum economic N fertilizer rate of up to 264 kg ha⁻¹ for canola. Porter (1993) reported that total N application of 135 kg ha⁻¹ gave maximum canola grain yield in a study in South Carolina. Nuttall et al. (1992) also found good response of canola yield to applied N. An experiment in England showed winter oilseed rape to require 200 kg N ha⁻¹ for optimum yield (Scott et al., 1973). Increasing prices of N fertilizer, desire to promote agricultural sustainability, pollution concern, and efforts to conserve natural resources have prompted researchers to

develop cropping systems that reduce N fertilizer applications and make more efficient use of organic N sources (Heichel and Barnes, 1984; Hargrove et al., 1988; Fauci and Dick, 1994; Sweeney and Moyer, 1994).

Farmers have used forage legumes in cropping systems for many years to take advantage of the N contribution of the legume and to enhance the productivity of a succeeding nonlegume crop (Hesterman, 1988). Many researchers have accepted that at least a portion of the major effect of legumes in crop rotations is their contribution of mineral N (Stickler et al., 1958; Bolton et al., 1976; Baldock et al., 1981; Martin and Touchton, 1983; Hesterman et al., 1987; Bruulsema and Christie, 1987; Scott et al., 1987; Badaruddin and Meyer, 1989). Green manuring was first utilized in ancient China and the practice has been defined as an enrichment of the soil by incorporating fresh plant material other than just plant residues (Pieters, 1927). Both legumes and non-legume crops are used as green manures, but from a N standpoint legumes are more beneficial as green manures because they fix atmospheric dinitrogen (Giddens et al., 1965). The use of green manures with various crops such as corn, wheat, rice, oats, cotton, and sugarbeets have been reported by various authors (Mahler and Auld, 1989), but very little literature exists on the use of green manures for canola. Numerous reports indicate that availability of green manure N depends mainly on type and quantity applied, time of incorporation, and the following crop (Mahler and Hemamda, 1993). Studies have also demonstrated that harvest management of legumes affects the quantity of N-rich herbage returned which consequently influences subsequent crop yields. Contribution of N at plowdown is greater was more from

legumes that are not harvested (Robinson, 1968; Groya and Sheaffer, 1985; Hesterman et al., 1986; Sparrow et al., 1995). However, Sheaffer et al. (1991) concluded that the greatest positive effect on yield of a subsequent corn crop from non-harvested legume plowdown is from legume stands older than 2 years. It is still unclear from previous research if harvesting an annual forage legume has any significant impact on the subsequent non-legume crop. Several researchers have attributed the effect of legumes on subsequent crop yields to both the effect of N and the net effect of all other contributions termed as "rotation effects" (Baldock et al., 1981; Hesterman, 1988; Russelle et al., 1987; Pierce and Rice, 1988).

Most legumes used as forage, green manure, or cover crops in the North Central USA are perennial species. However, perennial legumes may deplete soil moisture sufficiently to reduce the yield of the succeeding crop (Army and Hide, 1959; Hesterman et al., 1992). In many situations, such as winter canola or winter wheat, annual legumes may be beneficial. They may be planted in early spring so that they can mature before the optimum seeding time of the main crop, put on high quantity of biomass before plowdown, and decompose quickly to make nutrients available to the subsequent crop. Annual legumes can also be used as quality emergency forages (Shrestha et al., 1995). Annual medics (*Medicago* sp.) are self-pollinating true annuals. They flower, set seed, and die within one growing season (Bauchan and Sheaffer, 1994). Annual medics provide high quality forage (Bauchan et al., 1994; Shrestha et al., 1995) and are used on approximately 50 million hectares in Australia in pastures as a rotation crop (Crawford et al., 1989). Lake (1994) reported that

annual medics are known to improve soil structure, increase soil nitrogen, and reduce soil erosion. Berseem clover is an erect, cool-season annual legume believed to have originated in the region of Egypt and Syria (Baldrige et al., 1992). Berseem was introduced in the USA in 1896 and it has been grown successfully in Washington, Oregon, California, Arizona, and some parts of Florida (Kretschmer, 1964; Knight, 1985). It's greatest potential is as a green-chopped forage or pasture and it is known to be non-bloating (Dennis and Massengale, 1962). Berseem has been successfully used as a green manure and rotation crop (Baldrige et al., 1992; Westcott et al., 1995).

The N benefit to a subsequent crop is often reported as the N-fertilizer replacement value (FRV) and yield responses to previous legumes can be expressed on the basis of N-FRV. Fertilizer replacement value has been defined as the amount of N fertilizer required by a non-legume crop in monoculture to produce yields equivalent to those produced after incorporation of a legume (Hesterman, 1988). Various authors have used this method to report the N benefit of a legume to a subsequent crop (Clegg, 1982; Wright, 1990; Griffin and Harris, 1991; Hesterman et al., 1992; Pare et al., 1993; Jeranyama, 1995; Torbert et al., 1996). Fertilizer replacement values have been estimated for legumes like faba bean (*Vicia faba* L.), field pea (*Pisum sativum* L.), and lentil (*Lens culinaris* Moench) in barley (*Hordeum vulgare* L.) production (Wright, 1990). Similarly, Clegg (1982) estimated FRV of soybean (*Glycine max* [L.] Merr) to subsequent grain sorghum (*Sorghum bicolor* [L.] Moench). Hesterman et al. (1992) estimated the FRV of alfalfa and red clover (*Trifolium pratense* L.) to the

subsequent corn (*Zea mays* L.). Jeranyama (1995) estimated the FRV of annual medics to be 40 kg N ha⁻¹ on the succeeding corn. However, literature does not exist on estimation of FRV of annual medics and berseem clover on a subsequent canola crop. The objectives of this research were to: (i) quantify N accumulation at plowdown by annual medics and berseem clover managed as a forage or green manure; (ii) compare the response of canola to fertilizer N after a legume managed as a forage or green manure and after a nonlegume; and (iv) estimate the FRV of the previous crop management system on the subsequent canola.

MATERIALS AND METHODS

Field experiments were initiated in 1994 at two locations in Michigan: Michigan State University, Crop and Soils Farm, East Lansing on a Capac loam (fine-loamy, mixed, mesic Aeric Ochraqualfs) and on a Kalamazoo loam (fine-loamy, mixed, mesic Typic Hapludalf) at the Kellogg Biological Station (KBS), Hickory Corners. The experiments were repeated in 1995 at the same locations. Climatological data for 1994, 1995, and 1996 are shown in Table 1. In both years, P and K were applied to maintain soil test levels at or above those recommended for an alfalfa-canola rotation. Soil test data for the two years and two locations are summarized in Table 2. Seedbed preparation included conventional tillage and cultipacking.

First cycle: 1994/1995

Main plots of 24.3 by 2 m at East Lansing and 24.3 by 1.8 m at KBS were arranged in a randomized complete block design with four replications. The main plots included twelve treatments (Table 3). Barrel medic 'Mogul', burr medic 'Santiago', snail medic 'Sava', berseem clover, alfalfa 'Nitro', gamma medic 'Paraponto', and spring canola 'A114' were seeded with a small grain drill and cultipacked. Mogul, Santiago, Sava, and alfalfa seeds were inoculated with *Rhizobium meliloti* and berseem clover seeds were inoculated with *R. trifoli* prior to seeding. Paraponto seeds were not inoculated because it was chosen as an ineffective, non-

nodulating control treatment. Spring canola was seeded to create a continuous canola situation. The three nodulating annual medic species were chosen to represent three different growth habits, Mogul a semi-erect, Santiago a prostrate, and Sava an erect growing medic. The seeding rates of the legume species were determined at 270 pure live seeds (PLS) m^{-2} (Table 4). A preplant application of Eptam (*S*-ethyl dipropylthiocarbamate) at a rate of 3.3 kg ha^{-1} was incorporated in all the plots except those containing spring canola. Treflan (α,α,α -trifluoro-2,6-dinitro-*N,N*-dipropyl-*p*-toluidine) was preplant incorporated in the plots containing spring canola at a rate of 2 l a.i. ha^{-1} . Fertilizer N was applied at a rate of 20 kg N ha^{-1} in the plots containing spring canola. Both locations were irrigated with a total water application of 5 cm. All treatments designated as FOR, Paraponto, alfalfa, and canola were harvested approximately 60 days after planting (DAP) with a flail mower to a stubble height of 5 cm. Spring canola and fallow plots were roto-tilled after the harvest at 60 DAP. The FOR, Paraponto, and alfalfa treatments were allowed to regrow. Spring canola had not reached harvest maturity at this time and seed yields were not recorded. Green manure treatments were allowed to grow until approximately 90 DAP. All plots were plowed under by a mold board plow. Estimates of above-ground biomass were made prior to plowdown by taking 0.25 m^2 quadrat measurements. Biomass within the quadrat was hand clipped and adjusted to dry weight by drying in a forced-air oven at 60°C for 72 hours. Samples were ground to pass through a 1-mm screen in a cyclone mill (Wiley Corporation). Ground samples were subjected to the Hach procedure for total N determination (Hach et al., 1985) to obtain an estimate of N contained in the

biomass at plowdown. Roundup (Isopropylamine salt of glyphosate) was sprayed on the plots at East Lansing three days prior to plowdown. Planting, irrigation, harvest, and plowdown dates are summarized in Table 5.

Winter canola 'Ceres' was planted at a rate of 5 kg ha⁻¹ in all plots on 24 August 1994 at East Lansing with a small grain drill and on 26 August 1994 at KBS with a power drill and cultipacked. Plots at both locations were disked twice and Treflan was sprayed at a rate of 2 l a.i. ha⁻¹ and incorporated a week prior to planting winter canola. Main plots were split into 4 subplots and fertilizer N in the form of urea was applied as surface topdress at 4 rates (0, 50, 100, and 150 kg N ha⁻¹) on 22 March 1995 at East Lansing and 17 March 1995 at KBS. Each subplot was 6 by 2 m at East Lansing and 6 by 1.8 m at KBS and arranged in a split block design. A 90 cm alleyway was cut between the subplots by a flail mower on 22 May 1995 at East Lansing and 23 May 1995 at KBS. Bird netting was applied on the entire plot on 16 June 1995 at East Lansing and 27 June 1995 at KBS. Plots were harvested on 8 July 1995 at East Lansing and 12 July 1995 at KBS. Plant population of each treatment was estimated by counting number of stems within a 0.25 m² area immediately after harvest. Seeds were air dried and weighed. Seed moisture content was determined using seed moisture meter and seed yields were adjusted to a moisture content of 100 g kg⁻¹.

Soil Sampling and Analysis Soil samples were taken 3 times during the course of the experiment by a manual soil probe at two depths; 0-15 cm and 15-30 cm. The samples were immediately air-dried and ground to pass a 2 mm sieve. Total inorganic

N, nitrate-N, and ammonium-N were determined on each sample using KCl extraction procedure for inorganic N. The procedure consisted of shaking 10 g dry soil in 50 ml of 1 M KCl for 30 minutes. Inorganic N in filtered KCl extracts was assayed colorimetrically on a Lachat flow injector analyzer using Lachat Quickchem Method 12-107-04-1-A. The soil sampling dates are summarized in Table 6.

Second cycle: 1995/1996

The experiment was repeated in 1995 in different plots at the same two locations. Details of the plots are summarized in Table 2. Similar planting and cultural practices were used as in 1994. The same *Rhizobium* inoculation culture was used for alfalfa and berseem as in 1994 but the annual medics were inoculated with a 1:1 mixture of *R. meliloti* and Rhizobium special number 1 (Nitragin, Liphatech Inc.). Only East Lansing was irrigated with a total water application of 5 cm. Planting, irrigation, harvest, and plowdown dates are summarized in Table 5. Winter canola cv. Ceres was planted at a rate of 5 kg ha⁻¹ on 23 August 1995 at East Lansing and 24 August 1995 at KBS. Canola at East Lansing failed to germinate due to dry conditions and was replanted on 12 September 1995. Fertilizer N in the form of urea was applied at four rates (0, 50, 100, and 150 kg N ha⁻¹) on 18 March 1996 at KBS and 21 March 1996 at East Lansing. The severe winter in 1995/96 resulted in almost 100 per cent winter-kill of the canola at East Lansing. Roundup was sprayed on the plots at East Lansing on 17 May 1996 to kill weeds and the few surviving canola plants. Spring canola 'Cyclone' was planted on 20 May 1996 at East Lansing, but it

failed to germinate because of soil crusting. Re-planting was done by no-till drill on 28 May 1996. Only 3 replications were planted as the area containing the fourth replication was too wet for field activities and use of machinery. Alleyways were cut between subplots as in 1995. Bird netting was put on at KBS on 1 July 1996 and 9 August 1996 at East Lansing. The plots were harvested on 16 July 1996 at KBS and on 28 August 1996 at East Lansing. Seed yield of each treatment and plant population was determined similarly as in 1995. Similar soil sampling and analysis procedures were followed as in the previous year. Soil sampling dates are summarized in Table 6.

Statistics

Analysis of variance was performed on the data for N in biomass at plowdown, canola seed yield, canopy height, plant population, and soil inorganic-N values within each location because significant treatment X location interactions were detected. Significant differences among treatments were determined with an *F*-test and mean separation was done using Fisher's Least Significant Difference (LSD) where the *F*-test denoted significance ($P \leq 0.05$). Single degree of freedom orthogonal contrasts were used to compare canola yield under green manure and forage treatments, berseem and medics, and continuous and rotation treatments.

RESULTS AND DISCUSSION

Biomass and nitrogen content of the legumes at plowdown

Estimates of the amount of N in above ground biomass being plowed under showed that there were significant differences among treatments and species (Table 7). Berseem as a green manure had a significantly higher N content at plowdown than the other species at East Lansing and KBS in 1994. In 1995, Mogul and berseem as green manure had significantly higher N content at plowdown than the other species at both locations. Contrasts showed that the legume species when managed as a green manure had a significantly higher amount of N being plowed down than when managed as a forage. This was due to the fact that there was significantly higher amount of above ground biomass at the time of plowdown in the GM treatments than the FOR treatments at both locations in both years. However, the N concentration in the biomass was generally significantly higher in the FOR treatments than the GM treatments showing that N concentration in the regrowth of the biomass was higher when the plants are harvested at 60 DAP than the unharvested plants. The contrasts also showed that there was no significant difference between Paraponto (ineffective control) and the N-fixing legume treatments in terms of amount of N at plowdown in East Lansing in 1995. This was primarily due to the high biomass of Paraponto at plowdown rather than differences in N concentration. The amount of N in above ground biomass at plow down was not correlated with the average grain yield of succeeding canola.

Canola grain yield

Severe winter-kill caused almost 100 % loss of canola plants at East Lansing in 1996, while at KBS, the loss was about 33 % compared to the plant population in 1995. Spring canola was re-planted at East Lansing. Therefore, interactions for location X year, and year X main treatment were not analyzed. The main treatment X N level interactions were not significant at the 0.05 level; therefore data for canola grain yield were pooled and are presented for each main treatment averaged over N application rates. Canola yields under different cropping systems and N levels are summarized in Appendix Tables A.1 to A.4.

Neither preceding crop nor management practice had significant effect on canola grain yield in either year at East Lansing or in 1996 at KBS (Table 8). However, in 1995, species and management practices were associated with significant differences in the subsequent canola yield at KBS. Highest canola yields were obtained from the plots in which berseem had been managed as a green manure. The lowest yields were obtained from plots in which Santiago had been managed as a forage. The canola yield following the legumes managed as green manure was significantly higher than when the legumes were managed as forage. In 1995, at East Lansing, canola grain yield following berseem FOR was the highest, but was not significantly different from canola yield following other cropping systems. Orthogonal contrasts indicated no significant difference in canola grain yield under a continuous canola cropping system versus a crop rotation system (Table 7). Yields were higher when a crop rotation was followed but differences were not significant at a 0.05 level.

Contrasts also indicated that harvesting the preceding annual legume as a forage at 60 DAP and plowing down the regrowth and residue at 90 DAP or plowing down the entire biomass as green manure at 90 DAP had no differential effect on canola grain yield except at KBS in 1995 (Table 8). Canola following berseem clover managed either as a forage or green manure was similar to canola following all the other annual medics managed as a forage or green manure in East Lansing and KBS in 1996. However, in 1995, canola yield following berseem clover was significantly higher than canola yield following annual medics in both locations.

As expected, canola yield at East Lansing in 1996 was very low due to delayed planting. The average yield under all treatments was less than 1 Mg ha⁻¹. There were no significant differences among the main treatments in terms of effect on the following canola yield. Contrasts also showed that canola yield under a crop rotation system and under a continuous canola system was not significantly different. Similarly, canola yield following the GM or FOR, and berseem or medic treatments were not significantly different.

It is apparent from Table 8 that canola grain yields at KBS in 1996 were affected by winter-kill. Canola response to the treatments was influenced by the severe weather conditions in 1996 as it did not simulate the responses in 1995. Yields were generally lower in 1996 than 1995 under all treatments. Canola plant population and yield was respectively 33 % and 9 % lower in 1996 compared to that in 1995. The highest yield of canola grain was obtained when canola followed Mogul FOR but it was not significantly different from the other cropping systems at the 0.05 level.

It can be inferred that the canola yield following berseem clover managed either as a forage or green manure was generally higher than the other treatments even though statistical significance at 0.05 level was obtained only at KBS in 1995. In general, harvesting the preceding annual legume as a forage at 60 DAP and plowing down the regrowth and residue at 90 DAP or plowing down the entire biomass as green manure at 90 DAP had no significant effect on canola grain yield.

Canola plant population

Differences in cropping system had no effect on plant population of the subsequent canola at both locations in 1995 (Table 9). Canola plant population was generally higher at KBS than at East Lansing. Canola experienced severe winter-kill in 1996. Winter-kill may have been due to colder temperatures and lack of snow cover in 1996 compared to 1995 (Table 1), and heaving of canola plants. As a result, spring canola was planted at East Lansing to measure FRV's of the legumes. As in 1995, the preceding cropping system had no effect on canola population at KBS in 1996. Although, the loss in plant population was 33 %, the loss in canola grain yield was only about 9 %. This indicates that the loss in plant population may have been compensated by more branching and subsequently more pods per plant due to less inter-plant competition for resources.

Canola response to nitrogen under different cropping systems

The effect of nitrogen fertilizer on canola grain yield was highly significant at both locations in 1995 and 1996. Trend analysis showed that N had significant ($P \leq 0.05$) linear and quadratic effects on canola grain yield at East Lansing in 1995 and at KBS in 1996 (Table 8). The quadratic effect of N at KBS in 1995 can be explained by the fact that the plants had lodged in several plots which had the highest N level. Whereas, at East Lansing it was observed that the spring canola plots with the highest N level were generally greener and less mature than the plots with a lower N level thus affecting the yield at 150 kg N ha⁻¹ level. Figures 1 to 4 show the degree of response of canola to fertilizer N under various cropping systems in 1995 and 1996 at East Lansing and KBS. Regression equations describing response curves of canola yield to fertilizer N in Figures 1 to 4 are listed in Table 10.

Nitrogen fertilizer replacement values (FRV)

It has been suggested that, for a FRV to be valid and useful there must be a significantly higher yield of a crop following a legume than following a nonlegume control when no N fertilizer is used in either system (Hesterman et al., 1992). Based on this suggestion FRV's of the legumes were non-estimable in this study as canola yield following a legume and the nonlegume control at 0 N level was not significantly different in either year at both locations. Several researchers have attributed increased yields in a crop following legumes to effects termed as "rotation effects" which includes improved soil physical, chemical, and biological properties (Ries et al., 1977;

Russelle et al., 1987; Torbert et al., 1996). However, rotation effects were not visible in this experiment as no significant differences between treatments were found in canola yield. Paraponto was used in this experiment in order to differentiate non-N effects from N-effects of the nodulating legumes. However, the results obtained in this experiment did not help in differentiating these effects.

Soil nitrate and ammonium levels

The soil tests for NO_3 and NH_4 at three different periods during the course of the experiment showed that there were no significant differences between treatments at both East Lansing and KBS in 1995 (Table 11 and 12). The NO_3 levels under each treatment were generally higher at East Lansing than at KBS. However, time trends of NO_3 and NH_4 levels were evident. The NH_4 levels were higher than the NO_3 levels at the second sampling in October 1994 at both locations. The NH_4 levels at this sampling date were almost twice as high in KBS than at East Lansing. However, in 1995 the peaks of NH_4 at the October sampling date was not so evident as in 1994. Significant differences were found in the NO_3 levels both at East Lansing and KBS only in the August sampling date in 1995. The NO_3 levels in the fallow and continuous canola plots were higher than in the other treatments at East Lansing. However, the fallow plot was not significantly different from the plot with alfalfa. This indicates that nitrogen from the legumes had not yet mineralized at this sampling date. Similarly, the highest NO_3 levels were in the fallow plots at KBS. No significant differences were found in NH_4 levels. At East Lansing, the March 1996

samples showed higher levels of NO_3 than the samples of March 1995. It may be recalled that the canola plants had winter-killed in 1996 and there was no uptake of nitrogen. This suggests that NO_3 is generally taken up by the plants at or before this sampling date.

SUMMARY

The presence of an annual legume as a preceding crop did not result in significantly higher yields of the subsequent canola crop. Fertilizer N had a significant linear and quadratic effect on the canola yield and the trend of the effect was similar for canola grown under different cropping systems. The practice of harvesting the annual legume as a forage 60 DAP and plowing down the regrowth at 90 DAP versus the practice of plowing down the entire above ground biomass at 90 DAP without harvesting it as a forage showed no differences in terms of the yield of the subsequent canola crop. However, significant differences between these practices were obtained at KBS in 1995, where the harvested treatments were associated with significantly lower canola yields than the unharvested treatments. This suggests that it is possible to take one harvest of annual legumes as a forage and still get benefits equivalent to the unharvested legumes in terms of contribution to the yield of the following crop. The yield of canola following berseem clover was generally higher than when following an annual medic. The amount of above ground biomass and N content at plowdown had no significant effect in the yield of the following canola crop. There were generally no significant differences in the soil NO_3 and NH_4 levels between treatments at various sampling dates. This could be due to the leaching of nitrates or lack of synchrony between the release of N from the legume residues and uptake of N by the canola plants. The legumes did not produce any significant FRV thus questioning their use in reducing fertilizer N need in canola under such cropping systems. The annual medic

species used in this experiment are not quite adapted to this region (Michigan) in terms of use as a green manure or as a rotation crop. However, berseem clover generally produced higher biomass, higher forage quality (Shrestha et al., 1995), and had a significant effect on the yield of the following canola crop in one year.

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Table 1. Climatological data from May 1994 to July 1996 at East Lansing and Kellogg Biological Station (KBS), Michigan.

Year	Month	East Lansing		KBS	
		Tot. Precip.	Mean Temp.	Tot. Precip.	Mean Temp.
		mm	°C	mm	°C
1994	May	46.2	12.7	3.96	15.8
	Jun.	185.9	19.8	174.4	21.5
	Jul.	121.2	20.9	160.2	22.4
	Aug.	143.3	18.6	119.5	21.9
	Sept.	118.9	16.7	29.6	17.9
	Oct.	80.8	10.7	73.4	12.0
	Nov.	120.7	5.7	106.7	6.9
	Dec.	39.9	-0.2	40.5	1.2
1995	Jan.	15.0	-3.8	31.2	-2.6
	Feb.	27.2	-6.0	13.1	-4.2
	Mar.	35.6	2.0	35.6	3.7
	Apr.	69.3	5.2	76.8	6.7
	May	63.5	12.6	72.7	14.8
	Jun.	42.2	19.8	92.2	21.6
	Jul.	100.6	21.4	82.9	24.4
	Aug.	116.1	23.2	110.4	24.8
	Sept.	32.3	14.6	48.4	16.1
	Oct.	69.1	11.2	58.9	12.0
	Nov.	78.5	-0.7	90.8	0.8
	Dec.	22.6	-5.1	14.7	-3.5
1996	Jan.	32.0	-6.5	20.3	-5.1
	Feb.	19.1	-5.2	32.1	-3.4
	Mar.	12.7	-2.1	11.4	-0.8
	Apr.	98.0	6.1	81.9	7.1
	May	71.9	12.6	70.3	14.5
	Jun.	140.5	19.6	130.4	21.6
	Jul.	29.5	19.7	2.56	21.3

Table 2. Initial soil test values at East Lansing and KBS in 1994 and 1995.

Year and Location	Soil pH	Avail. P	Exch. K
1994		----- kg ha ⁻¹ -----	
East Lansing	7.6	82	228
KBS	7.3	80	130
1995			
East Lansing	7.3	82	159
KBS	7.6	74	226

Table 3. List of main treatments at East Lansing and KBS in 1994 and 1995.

Treatment No.	Treatment description
1	Fallow
2	Spring canola cv. A114
3	'Paraponto' gamma medic (Ineffective)
4	'Nitro' alfalfa
5	'Mogul' barrel medic managed as forage (FOR)
6	'Mogul' barrel medic managed as green manure (GM)
7	'Santiago' burr medic managed as forage (FOR)
8	'Santiago' burr medic managed as green manure (GM)
9	'Sava' snail medic managed as forage (FOR)
10	'Sava' snail medic managed as green manure (GM)
11	Berseem clover managed as forage (FOR)
12	Berseem clover managed as green manure (GM)

Table 4. Seeding rate of the species in the main treatments at East Lansing and KBS in 1994 and 1995.

Species	Seeding rate
	kg ha ⁻¹
'Nitro' Alfalfa	20
'Mogul' Barrel medic	15
'Santiago' Burr medic	15
'Sava' Snail medic	32
'Paraponto' Gamma medic	25
Berseem clover	12
Spring canola	5

Table 5. Planting, irrigation, harvest, and plowdown dates in 1994 and 1995 at East Lansing and Kellogg Biological Station (KBS), Michigan.

Location	Planting	Irrigation	Harvest1	Harvest2	Plowdown
1994					
East Lansing	13 May	25 May	18 July	8 August	8 August
KBS	6 May	3 May	11 July	9 August	9 August
1995					
East Lansing	12 May	21 May	17 July	14 August	21 August
KBS	8 May	-	13 July	10 August	21 August

Table 6. Summary of soil sampling dates at East Lansing and KBS in 1994, 1995 and 1996.

Year	Location	Soil sampling dates
1994/95	East Lansing	23 Aug. '94, 17 Oct. '94, 22 Mar. '95
1994/95	KBS	18 Aug. '94, 12 Oct. '94, 17 Mar. '95
1995/96	East Lansing	23 Aug. '95, 30 Oct. '95, 11 Apr. '96
1995/96	KBS	16 Aug. '95, 23 Oct. '95, 18 Mar. '96

Table 7. Biomass, nitrogen concentration, and nitrogen content of the various treatments at plowdown at East Lansing and KBS in 1994 and 1995.

Location & Treatment	1994			1995		
	DM	N conc.	N cont.	DM	N conc.	N cont.
	Mg ha ⁻¹	g kg ⁻¹	kg ha ⁻¹	Mg ha ⁻¹	g kg ⁻¹	kg ha ⁻¹
East Lansing						
Paraponto	1.15	17.1	19.6	2.25	22.5	50.2
Alfalfa	1.55	30.0	47.1	1.94	29.8	58.0
Mogul (GM)	3.31	21.9	78.6	2.61	26.8	70.2
Mogul (FOR)	1.41	22.6	35.4	1.99	28.0	55.4
Santiago (GM)	1.98	15.7	30.2	1.49	25.1	37.2
Santiago (FOR)	1.09	22.3	24.5	1.14	28.4	32.0
Sava (GM)	1.57	20.0	31.7	Traces	-	-
Sava (FOR)	0.65	21.0	13.8	Traces	-	-
Berseem (GM)	4.98	24.8	122.9	3.25	25.3	82.3
Berseem (FOR)	1.62	34.6	56.1	2.08	28.4	58.7
LSD (0.05)	1.23	4.8	31.1	0.8	3.0	21.9
CV(%)	43.5	13.9	45.9	25.7	6.4	26.8
Contrasts						
GM vs FOR	**	**	**	**	**	*
Ber. vs med.	**	**	**	**	NS	**
Para. vs leg.	NS	NS	**	NS	**	NS
KBS						
Paraponto	1.88	18.9	36.7	0.98	28.8	29.6
Alfalfa	1.33	32.7	42.8	1.65	33.7	55.3
Mogul (GM)	3.53	29.1	104.3	3.30	26.2	87.2
Mogul (FOR)	2.56	27.8	70.5	1.80	26.9	47.5
Santiago (GM)	1.12	22.1	24.9	1.94	32.6	62.3
Santiago (FOR)	1.09	20.8	22.3	0.98	36.2	35.2
Sava (GM)	1.36	20.5	27.9	Traces	-	-
Sava (FOR)	1.05	23.4	26.4	Traces	-	-
Berseem (GM)	3.55	30.7	110.0	4.43	22.6	100.4
Berseem (FOR)	2.09	31.3	65.4	1.64	29.3	48.1
LSD (0.05)	0.7	5.1	27.8	0.7	4.2	18.7
CV(%)	26.4	13.7	36.0	22.5	9.8	22.1
Contrasts						
GM vs FOR	**	NS	**	**	**	*
Ber. vs med.	**	**	**	NS	**	NS
Para. vs leg.	NS	**	**	**	NS	**

GM = Green manure

FOR = Forage

Ber. = Berseem

Med. = Medics

Para. = Paraponto (ineffective) Leg. = Legumes (effective)

*, ** Significant at the 0.05 and 0.01 levels respectively.

NS = Not significant at the 0.05 level.

Table 8. Average canola yields under different cropping systems and nitrogen rates at East Lansing and KBS in 1995 and 1996.

Cropping System	East Lansing		KBS	
	1995	1996	1995	1996
	----- Mg ha ⁻¹ -----			
Fallow-canola (F-C)	2.31	0.72	3.18	2.80
Canola-canola (C-C)	2.33	0.71	3.15	2.92
Paraponto-canola (P-C)	2.38	0.58	3.17	2.89
Alfalfa-canola (A-C)	2.54	0.63	3.29	2.89
Mogul GM-canola (MG-C)	2.48	0.67	3.16	2.86
Mogul FOR-canola (MF-C)	2.45	0.64	3.16	3.04
Santiago GM-canola (SaG-C)	2.32	0.66	3.24	2.91
Santiago FOR-canola (SaF-C)	2.29	0.68	2.95	2.81
Sava GM-canola (SvG-C)	2.31	0.78	3.31	2.96
Sava FOR-canola (SvF-C)	2.47	0.53	3.04	3.03
Berseem GM-canola (BG-C)	2.53	0.70	3.43	2.93
Berseem FOR-canola (BF-C)	2.61	0.72	3.27	2.87
LSD (0.05)	NS	NS	0.26	NS
Contrasts				
N linear	**	**	**	**
N quadratic	NS	**	**	NS
N cubic	NS	NS	NS	NS
Rotation vs cont.canola	NS	NS	NS	NS
GM vs FOR	NS	NS	**	NS
Medics vs Berseem	**	NS	**	NS
CV%	8.1	16.2	7.6	7.6

** Significant at the 0.01 level; NS = nonsignificant at 0.05 level.

GM = Green manure

FOR = Forage

Table 9. Average canola plant population under different cropping systems at East Lansing and KBS in 1995 and 1996.

Cropping System	East Lansing		KBS	
	1995	1996	1995	1996
----- Plants ha ⁻¹ (in thousands)-----				
F-C	1350	1640	1610	1100
C-C	1210	1350	1360	1100
P-C	1290	1560	1710	1030
A-C	1080	1310	1520	980
MG-C	1090	1360	1610	1040
MF-C	1300	1430	1200	1070
SaG-C	1380	1470	1550	980
SaF-C	1290	1560	1830	1090
SvG-C	1040	1550	1890	1030
SvF-C	1180	1650	1450	1020
BG-C	1270	1560	1620	1000
BF-C	1200	1320	1540	1070
	NS	NS	NS	NS
CV%	15.5	10.9	23.0	9.5

Table 10. Regression equations on response of canola to fertilizer nitrogen under different cropping systems at East Lansing and KBS in 1995 and 1996.

Cropping System	Equation	1995 r^2	Equation	1996 r^2
East Lansing				
F-C	$Y = 1.81 + 0.007N$	0.95	$Y = 0.62 + 0.003N - 0.00002N^2$	0.96
C-C	$Y = 1.72 + 0.008N$	0.97	$Y = 0.53 + 0.005N - 0.00002N^2$	0.99
P-C	$Y = 1.76 + 0.008N$	0.98	$Y = 0.41 + 0.005N - 0.00002N^2$	0.96
A-C	$Y = 2.10 + 0.006N$	0.87	$Y = 0.53 + 0.006N - 0.00004N^2$	0.90
MG-C	$Y = 2.06 + 0.006N$	0.95	$Y = 0.60 + 0.002N - 0.00001N^2$	0.67
MF-C	$Y = 1.93 + 0.007N$	0.98	$Y = 0.52 + 0.004N - 0.00002N^2$	0.92
SaG-C	$Y = 1.81 + 0.007N$	0.93	$Y = 0.53 + 0.003N - 0.00001N^2$	0.99
SaF-C	$Y = 1.77 + 0.007N$	0.94	$Y = 0.56 + 0.004N - 0.00002N^2$	0.89
SvG-C	$Y = 1.80 + 0.007N$	0.97	$Y = 0.65 + 0.002N - 0.00001N^2$	0.96
SvF-C	$Y = 1.99 + 0.006N$	0.91	$Y = 0.44 + 0.003N - 0.00001N^2$	0.89
BG-C	$Y = 2.06 + 0.006N$	0.78	$Y = 0.55 + 0.006N - 0.00003N^2$	0.87
BF-C	$Y = 2.15 + 0.006N$	0.94	$Y = 0.64 + 0.003N - 0.00001N^2$	0.99
KBS				
F-C	$Y = 2.76 + 0.02N - 0.00009N^2$	0.99	$Y = 2.65 + 0.002N$	0.72
C-C	$Y = 2.78 + 0.01N - 0.00004N^2$	0.97	$Y = 2.52 + 0.005N$	0.90
P-C	$Y = 2.89 + 0.01N - 0.00004N^2$	0.94	$Y = 2.63 + 0.003N$	0.91
A-C	$Y = 2.91 + 0.01N - 0.00005N^2$	0.91	$Y = 2.66 + 0.003N$	0.85
MG-C	$Y = 3.05 + 0.01N - 0.00009N^2$	0.99	$Y = 2.59 + 0.003N$	0.92
MF-C	$Y = 2.85 + 0.01N - 0.00007N^2$	0.93	$Y = 2.79 + 0.003N$	0.93
SaG-C	$Y = 2.93 + 0.01N - 0.00004N^2$	0.92	$Y = 2.75 - 0.001N$	0.21
SaF-C	$Y = 2.61 + 0.01N - 0.00002N^2$	0.99	$Y = 2.55 + 0.003N$	0.94
SvG-C	$Y = 3.00 + 0.01N - 0.00004N^2$	0.99	$Y = 2.66 + 0.004N$	0.93
SvF-C	$Y = 2.68 + 0.01N - 0.00005N^2$	0.83	$Y = 2.66 + 0.005N$	0.99
BG-C	$Y = 3.14 + 0.01N - 0.00002N^2$	0.98	$Y = 2.74 + 0.003N$	0.96
BF-C	$Y = 3.07 + 0.002N - 0.00001N^2$	0.86	$Y = 2.51 + 0.005N$	0.99

N = Nitrogen (kg ha^{-1})

Table 11. Soil inorganic nitrogen levels under selected treatments at various dates at a depth of 0-15 cm at East Lansing and KBS in 1994/95 and 1995/96.

Location & Treatment	1994/1995				1995/96			
	Aug. 94		Oct. 94		Aug. 95		Oct. 95	
	NO3	NH4	NO3	NH4	NO3	NH4	NO3	NH4
mg kg-1								
East Lansing								
F-C	7.7	3.2	1.7	7.3	1.6	1.7	0.8	1.6
C-C	7.3	3.8	1.6	5.3	1.6	2.6	2.1	2.1
P-C	5.4	3.3	1.7	8.3	1.6	1.4	0.9	1.5
A-C	7.5	3.5	2.0	5.4	1.7	1.6	0.8	1.5
MG-C	8.4	4.1	1.7	5.9	1.6	5.5	1.6	1.5
MF-C	6.8	3.9	1.7	7.4	1.7	1.7	1.2	1.6
BG-C	8.2	3.5	2.1	5.1	1.7	1.9	1.2	1.4
BF-C	8.0	4.0	1.6	7.1	1.5	1.5	1.3	1.5
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
KBS								
F-C	3.6	3.9	1.5	16.9	2.1	2.6	2.5	1.8
C-C	3.0	4.0	1.8	16.4	1.9	2.8	1.9	1.9
P-C	2.5	3.7	1.4	16.5	1.9	2.6	2.4	1.7
A-C	2.9	5.4	1.5	15.3	2.0	2.9	3.1	2.1
MG-C	2.8	5.2	1.5	15.3	1.9	2.9	1.7	2.0
MF-C	4.1	6.4	1.2	14.3	1.8	2.6	2.2	1.9
BG-C	2.0	4.5	1.4	14.2	1.5	2.6	2.3	1.8
BF-C	2.7	5.9	1.7	15.6	1.8	2.7	2.0	1.9
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Table 12. Soil inorganic nitrogen levels under selected treatments at various dates at a depth of 15-30 cm at East Lansing and KBS in 1994/95 and 1995/96.

Location & Treatment	1994/1995				1995/96			
	Aug. 94		Oct. 94		Mar. 95		Aug. 95	
	NO3	NH4	NO3	NH4	NO3	NH4	NO3	NH4
----- mg kg-1 -----								
East Lansing								
F-C	7.5	2.2	1.4	5.2	1.6	1.2	2.9	5.9
C-C	7.3	2.2	1.6	4.6	1.7	1.4	5.5	5.0
P-C	4.3	2.5	2.4	5.4	1.8	0.9	2.7	4.6
A-C	6.8	2.7	1.6	4.8	1.7	1.3	1.8	5.0
MG-C	5.9	2.8	1.6	5.3	1.6	0.9	2.5	4.9
MF-C	6.6	3.9	1.7	9.2	1.5	2.9	2.3	4.1
BG-C	5.6	2.8	2.2	5.5	1.8	0.8	2.9	5.0
BF-C	6.0	2.7	2.4	4.5	1.4	1.4	2.7	4.6
LSD (0.05)	NS	NS	NS	NS	NS	NS	2.0	NS
KBS								
F-C	1.6	2.9	1.9	15.7	2.1	2.4	9.9	5.1
C-C	3.2	3.1	1.5	17.7	2.1	2.0	8.3	5.1
P-C	2.1	3.6	1.6	15.5	2.0	2.6	4.4	6.0
A-C	1.7	3.4	2.6	16.2	1.9	2.2	5.3	6.2
MG-C	3.1	5.0	2.5	15.8	1.8	3.0	3.0	7.2
MF-C	2.8	3.9	1.4	13.6	1.6	2.1	6.5	6.5
BG-C	3.1	3.9	1.1	16.4	1.6	2.2	5.0	5.5
BF-C	2.6	3.3	1.1	13.1	1.7	2.4	4.3	6.8
LSD (0.05)	NS	NS	NS	NS	NS	NS	3.3	NS

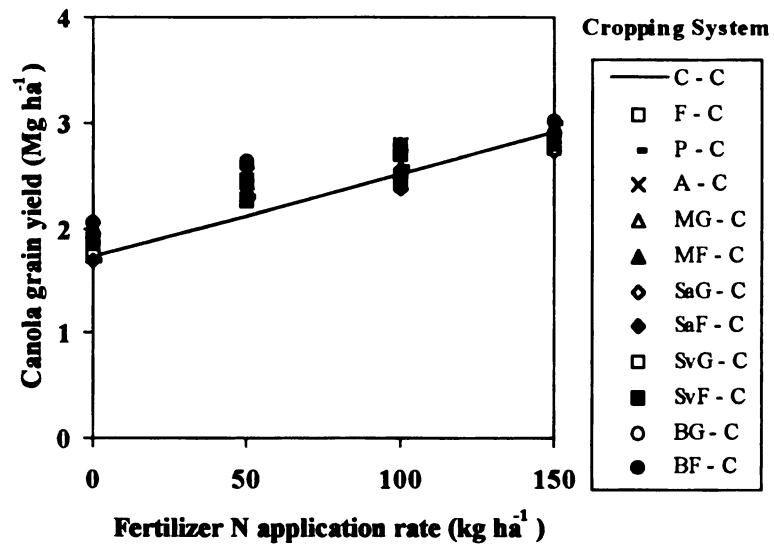


Figure 1. Response of canola to fertilizer N under different cropping systems at East Lansing in 1995.

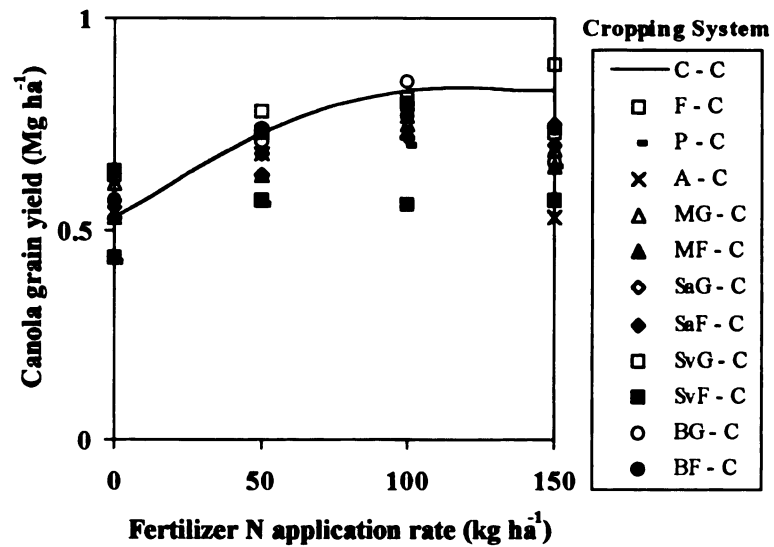


Figure 2. Response of canola to fertilizer N under different cropping systems at East Lansing in 1996.

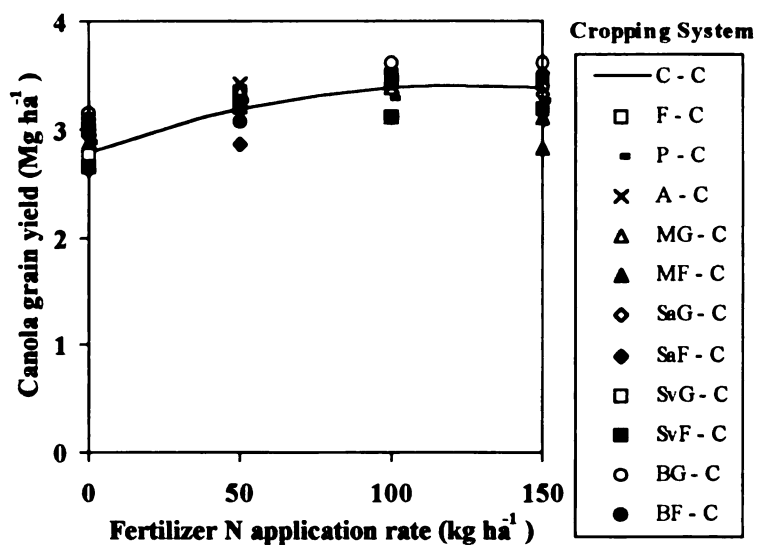


Figure 3. Response of canola to fertilizer N under different cropping systems at Kellogg Biological Station (KBS) in 1995.

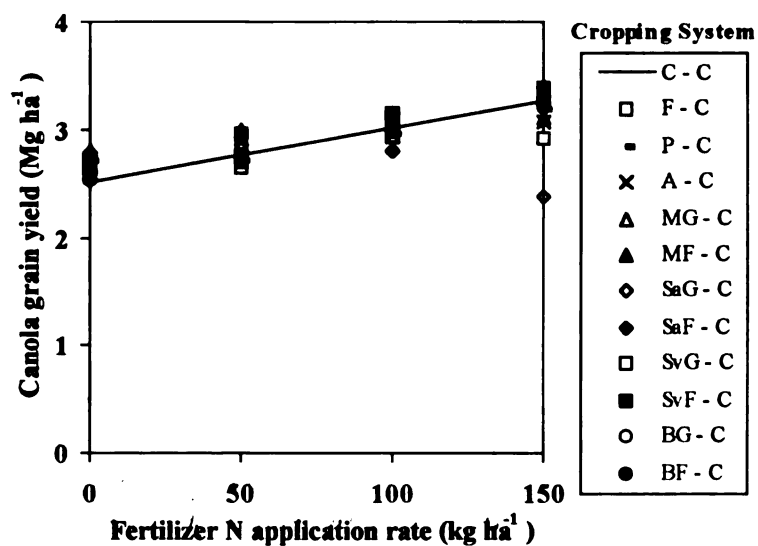


Figure 4. Response of canola to fertilizer N under different cropping systems at Kellogg Biological Station (KBS) in 1996.

APPENDIX

Table A.1. Canola yield under different cropping systems and fertilizer nitrogen levels at East Lansing in 1995.

Cropping System	Fertilizer N (kg N ha ⁻¹)			
	0	50	100	150
	----- Canola yield (Mg ha ⁻¹) -----			
Fallow-canola (F-C)	1.73	2.28	2.45	2.76
Canola-canola (C-C)	1.66	2.25	2.46	2.94
Paraponto-canola (P-C)	1.68	2.30	2.57	2.99
Alfalfa-canola (A-C)	1.98	2.51	2.80	2.84
Mogul GM-canola (MG-C)	2.02	2.44	2.54	2.94
Mogul FOR-canola (MF-C)	1.90	2.24	2.22	2.98
Santiago GM-canola (SaG-C)	1.69	2.28	2.56	2.73
Santiago FOR-canola (SaF-C)	1.69	2.28	2.38	2.81
Sava GM-canola (SvG-C)	1.72	2.25	2.50	2.79
Sava FOR-canola (SvF-C)	1.87	2.45	2.69	2.85
Berseem GM-canola (BG-C)	1.85	2.64	2.79	2.86
Berseem FOR-canola (BF-C)	2.05	2.59	2.77	3.01
LSD(0.05)	NS	0.24	NS	NS

Table A.2. Canola yield under different cropping systems and fertilizer nitrogen levels at Kellogg Biological Station (KBS) in 1995.

Cropping System	Fertilizer N (kg N ha ⁻¹)			
	0	50	100	150
	----- Canola yield (Mg ha ⁻¹) -----			
Fallow-canola (F-C)	2.76	3.33	3.46	3.18
Canola-canola (C-C)	2.76	3.21	3.29	3.32
Paraponto-canola (P-C)	2.87	3.27	3.28	3.27
Alfalfa-canola (A-C)	2.88	3.42	3.40	3.46
Mogul GM-canola (MG-C)	3.06	3.37	3.38	2.83
Mogul FOR-canola (MF-C)	2.87	3.20	3.44	3.11
Santiago GM-canola (SaG-C)	2.95	3.20	3.49	3.32
Santiago FOR-canola (SaF-C)	2.62	2.86	3.12	3.19
Sava GM-canola (SvG-C)	3.00	3.34	3.49	3.42
Sava FOR-canola (SvF-C)	2.64	3.21	3.11	3.19
Berseem GM-canola (BG-C)	3.15	3.37	3.61	3.61
Berseem FOR-canola (BF-C)	3.10	3.08	3.42	3.50
LSD(0.05)	NS	NS	NS	0.40

Table A.3. Canola yield under different cropping systems and fertilizer nitrogen levels at East Lansing in 1996.

Cropping System	Fertilizer N (kg N ha ⁻¹)			
	0	50	100	150
	----- (Canola yield Mg ha ⁻¹) -----			
Fallow-canola (F-C)	0.63	0.73	0.80	0.73
Canola-canola (C-C)	0.52	0.75	0.80	0.79
Paraponto-canola (P-C)	0.42	0.56	0.70	0.65
Alfalfa-canola (A-C)	0.54	0.68	0.77	0.53
Mogul GM-canola (MG-C)	0.61	0.63	0.75	0.69
Mogul FOR-canola (MF-C)	0.53	0.63	0.73	0.65
Santiago GM-canola (SaG-C)	0.53	0.63	0.72	0.75
Santiago FOR-canola (SaF-C)	0.57	0.68	0.80	0.69
Sava GM-canola (SvG-C)	0.64	0.78	0.81	0.89
Sava FOR-canola (SvF-C)	0.43	0.57	0.56	0.57
Berseem GM-canola (BG-C)	0.57	0.71	0.85	0.66
Berseem FOR-canola (BF-C)	0.64	0.74	0.77	0.74
LSD(0.05)	NS	NS	NS	NS

Table A.4. Canola yield under different cropping systems and fertilizer nitrogen levels at Kellogg Biological Station (KBS) in 1996.

Cropping System	Fertilizer N (kg N ha ⁻¹)			
	0	50	100	150
	----- Canola yield (Mg ha ⁻¹) -----			
Fallow-canola (F-C)	2.68	2.65	2.94	2.92
Canola-canola (C-C)	2.50	2.83	3.22	3.17
Paraponto-canola (P-C)	2.70	2.71	2.96	3.19
Alfalfa-canola (A-C)	2.67	2.75	3.09	3.07
Mogul GM-canola (MG-C)	2.65	2.71	2.94	3.12
Mogul FOR-canola (MF-C)	2.81	2.99	3.05	3.37
Santiago GM-canola (SaG-C)	2.79	2.87	2.97	2.37
Santiago FOR-canola (SaF-C)	2.53	2.77	2.81	3.24
Sava GM-canola (SvG-C)	2.71	2.76	3.10	3.26
Sava FOR-canola (SvF-C)	2.63	2.95	3.15	3.38
Berseem GM-canola (BG-C)	2.71	2.91	2.97	3.21
Berseem FOR-canola (BF-C)	2.54	2.70	3.02	3.23
LSD(0.05)	NS	NS	NS	NS

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