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Intercropping Corn with Lablab Bean, Velvet Bean, and Scarlet Runner Bean for Forage

Kevin L. Armstrong,* Kenneth A. Albrecht, Joseph G. Lauer, and Heathcliffe Riday

ABSTRACT

This experiment was designed to determine if intercropping corn (*Zea mays* L.) with climbing beans is a viable option to increase crude protein (CP) concentration in forage rather than purchasing costly protein supplements for livestock rations. In these experiments, corn was intercropped with three beans—lablab bean [*Lablab purpureus* (L.) Sweet], velvet bean [*Mucuna pruriens* (L.) D.C.], and scarlet runner bean (*Phaseolus coccineus* L.)—or grown in monoculture near Arlington and Lancaster, WI. Corn was sown in early May and late April in 2004 and 2005, respectively, and later thinned to 55,000 (low density) or 82,500 (normal density) plants ha^{-1}. Beans were sown in rows 8 cm on one side of the corn rows at 82,500 plants ha^{-1} 2 or 4 wk after corn planting. Averaged over four environments, mixture forage dry matter (DM) yields were similar. However the velvet bean and scarlet runner bean mixtures produced significantly higher forage DM yield, 1.2 Mg ha^{-1} and 0.89 Mg ha^{-1} more, respectively, in the late bean planting treatment. Beans, except scarlet runner bean, which was damaged by mold and insects, increased the CP concentration of all mixtures, with the greatest increases from the lablab bean (13%) and velvet bean (16%). The experiments show that lablab bean grown with corn has the greatest potential of the three beans to increase CP concentration above monoculture corn, without compromising forage yield or calculated milk ha^{-1} and increasing forage nutrient value.

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Abbreviations: CP, crude protein; DIP, degradable intake protein; DM, dry matter; IVTD, in vitro true digestibility; NDF, neutral detergent fiber; NDFd, neutral detergent fiber digestibility; NIRS, near infrared reflectance spectroscopy; SECV, standard error of cross validation; UIP, undegradable intake protein.

Corn (*Zea mays* L.) silage is a high-producing forage crop in the United States, with 2.4 million ha planted and 96.4 million Mg harvested in 2005 (USDA-NASS, 2006). Wisconsin was the top corn silage–producing state in the United States, with 13.6 million Mg harvested from 356,000 ha in 2005 (USDA-NASS, 2006). Corn silage is an important source of forage for dairy cattle in the United States because of its relatively consistent nutritive value, high yield, and high energy density compared with other forage crops (Coors and Lauer, 2001). One limitation to corn silage as a feed for dairy cows is low crude protein (CP) concentration; Darby and Lauer (2002) reported an average whole corn plant forage CP concentration of 73 g kg^{-1} across Wisconsin.

Because supplementing dairy rations with protein concentrate can be costly, alternatives have been explored. For example, Herbert et al. (1984) found intercropping corn and soybean [*Glycine max* (L.) Merr.] in alternating rows to be beneficial, with a 19 to 36% increase in CP concentration over monoculture corn

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with similar forage yields. Climbing beans have also been grown, with varying degrees of success, as an intercrop with corn. Kaiser and Lesch (1977) found that lablab bean [*Lablab purpureus* (L.) Sweet] increased CP concentration by 44% and lowered forage dry matter (DM) yield by 28%, with a lablab bean density of 108,000 plants ha^{-1} and a corn density ranging from 72,000 to 18,000 plants ha^{-1}. They reported up to a 78% increase in CP concentration from monoculture corn at a density of 54,000 plants ha^{-1} to an intercrop density of corn at 18,000 plants ha^{-1} and a constant lablab bean density of 108,000 plants ha^{-1}. Bryan and Materu (1987) found that intercropping cowpeas (*Vigna unguiculata* L. Walp) and corn increased CP concentration by 9% and did not lower forage DM yield compared with monoculture corn.

In Ghana, Haizel (1974) reported no difference in forage DM yield, harvested at full grain maturity, of monoculture corn or corn intercropped with cowpea in a good growing season. In Zimbabwe, Maasdorp and Titterton (1997) found varying results when intercropping climbing beans and corn. While lablab bean and scarlet runner bean (*Phaseolus coccineus* L.) did not produce much bean biomass in mixtures (less than 16%), velvet bean [*Mucuna pruriens* (L.) D.C.] accounted for nearly 30% of the intercrop mixture and depressed corn yield by 50%. The literature is inconclusive on the viability of such intercropping systems, and little information is available for production in cooler temperate regions.

This experiment was designed to determine if intercropping corn with beans is a viable option to increase CP concentration in forage rather than purchasing costly CP supplements for dairy cattle rations in a northern environment. The objectives of this research were to compare monoculture corn with corn–bean mixtures in terms of DM yield, nutritive value, potential milk production, and forage nutrient value and determine how these factors are affected by timing of bean planting and changes in corn density.

MATERIALS AND METHODS

Field experiments were conducted in 2004 and 2005 at the University of Wisconsin Agricultural Research Stations near Arlington (43°18′ N, 89°21′ W) and Lancaster (42°50′ N, 90°47′ W), WI. The experiments at Arlington were conducted on Plano silt loam (fine-silty, mixed, mesic Typic Argiudolls), on relatively flat and well-drained fields and at Lancaster on Rozetta silt loam (fine-silty, mixed, superactive, mesic Typic Hapludalfs), on a flat and well-drained field. The previous crop at Arlington was soybean both years. The previous crops at Lancaster were oat (*Avena sativa* L.) in 2004 and beans intercropped with corn in 2005. Before tillage, 170 and 135 kg ha^{-1} N as urea were applied at Arlington in 2004 and 2005, respectively. Before tillage, 180 kg ha^{-1} N as urea was applied at Lancaster in both years. Tillage operations included chisel plowing and field cultivation at Arlington and chisel plowing followed by a soil finisher at Lancaster in both years. Soil fertility levels at both locations were maintained at optimal levels for corn silage production (Kelling et al., 1998). Glyphosate [*N*-(phosphonomethyl)glycine] resistant corn hybrid DKC 50-20 was planted on 4 May 2004 and 25 Apr. 2005 at Arlington and 3 May 2004 and 26 Apr. 2005 at Lancaster. Corn was sown with 76.2-cm row spacing at 83,750 and 93,000 seeds ha^{-1} at both locations in 2004 and 2005, respectively, and later hand thinned to designated corn densities. Permethrin [(3-phenoxyphenyl) methyl(±)cis-trans 3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate] (6 g ha^{-1} a.i.), for control of corn wireworm [*Melanotus communis* (Gyll.)] and seed corn maggot [*Delia platura* (Meigen)], and carboxin (5,6-dihydro-2-methyl-N-phenyl-1,4-oxathin-3-carboxamide) (8 g ha^{-1} a.i.), for control of seed rots and decay, were applied at planting at Lancaster in both years. Glyphosate was spot sprayed for weed control at both locations, avoiding herbicide contact with the bean, along with hand weeding. Flumetsulam [*N*-(2,6-difluorophenyl)-5-methyl(1,2,4)triazolo(1,5-*a*)pyrimidine-2-sulfonamide] (28 g ha^{-1} a.i.) and s-metolachlor + safener [(1S)-2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide] (1.42 kg ha^{-1} a.i.) were applied pre-emergence to control weeds at both locations in 2005.

Experimental treatments included corn density, bean planting date, and species. The three bean species used were 'Rongai' lablab bean, velvet bean (speckled germplasm, from Sharad Phatak, University of Georgia), and 'Scarlet Emperor' scarlet runner bean. On the basis of a review of the literature, these bean species appear to have the best potential as intercrops with corn. Bean seeds were inoculated with appropriate rhizobia (Nitragin, Inc., Milwaukee, WI) and hand planted about 8 cm to one side of the corn rows at 2 or 4 wk after corn sowing. It was hypothesized that a delayed planting of beans alongside corn may be necessary to avoid excessive bean competition with corn development as noted by Maasdorp and Titterton (1997). When corn plants reached the V6 stage (Ritchie et al., 1992), they were hand thinned to a low density (55,000 plants ha^{-1}) and a normal density (82,500 plants ha^{-1}). Bean density was kept constant at 82,500 plants ha^{-1}. It was hypothesized that a lower corn density would allow greater bean development and subsequently greater CP in harvested forage.

The experimental design was a randomized complete block design in 2004 and 2005 with four replications at each location. Treatments were the factorial combination of two bean sowing dates, two corn densities, and three bean species. There was a corn control. Experimental units consisted of three corn rows in 2004 and four corn rows in 2005 with associated bean rows in 8.2-m long plots. The middle corn row in 2004 and one of the middle rows in each experimental unit in 2005 were harvested for forage.

On the day of harvest, representative corn and bean plants were removed from selected harvest rows with treatments of normal corn density and early bean planting date for near infrared reflectance spectroscopy (NIRS) equation development to estimate bean and corn proportions in the mixtures. Separated corn and bean plants were dried at

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60°C, weighed, and ground with a Christy hammer mill (Christy, Suffolk, UK) equipped with a 1-mm screen. Pure fractions (48 per experiment per year) and mixtures (36 per experiment per year) of corn and bean created by combining the pure fractions were used for NIRS equation development. Samples were scanned with a NIRSystems 6500 near infrared reflectance spectrophotometer (FOSS NIRSystems Inc., Eden Prairie, MN) equipped with a ring cup autosampler. Near-infrared reflectance spectra (1/R) were obtained between the wavelengths of 400 and 2498 nm. Data management and equation development were performed using WinISI 1.50 (Infrasoft International, Port Matilda, PA). Calibration statistics, [coefficient of determination [R^2] and standard error of cross validation [SECV]), for determining bean concentration in validation mixtures were SECV = 37 (R^2 = 0.99) and SECV = 20 (R^2 = 0.99) for separate equations developed in 2004 and 2005, respectively (Martens and Naes, 1989; Shenk and Westerhaus, 1991, 1994). Equations were used to predict bean concentration in mixtures and corn concentration was determined by subtracting bean concentration from total plot DM mass.

The middle row of each plot was harvested at the 50% kernel milk line stage (Afuakwa and Crookston, 1984) on 17 Sept. 2004 and 7 Sept. 2005 at Lancaster and 20 Sept. 2004 and 15 Sept. 2005 at Arlington. Harvest rows were chopped to a theoretical cutting length of 1 cm with a small, commercial forage harvester, and a 1-kg subsample was collected and dried at 60°C to determine DM concentration of the forage. The dried subsample was ground with a hammer mill equipped with a 1-mm screen.

Forages were analyzed for total N concentration by the Dumas method (AOAC, 1990) with an automated analyzer (LECO Model FP-528; LECO Corp., St. Joseph, MI). Crude protein concentrations were calculated by multiplying total N by 6.25. Neutral detergent fiber (NDF) concentrations were determined by the batch procedure outlined by ANKOM Technology Corp. (Fairport, NY). Subsamples (0.25 g each) were analyzed for in vitro true digestibility (IVTD) using rumen fluid from a lactating Holstein cow on a total mixed ration and buffer solution described by Goering and Van Soest (1970) with the Daisy II[200] in vitro incubator and the ANKOM[200] fiber analyzer (ANKOM Technology Corp., Fairport, NY). Neutral detergent fiber digestibility (NDFd) was calculated from the NDF and IVTD values as $100\{[\text{NDF} - (100 - \text{IVTD})]/\text{NDF}\}$. Ash concentration was determined by combustion of a 1.0-g subsample at 600°C for 2 h (data not shown but used in milk production models). Starch concentrations were determined by the procedures of Rong et al. (1996) and Owens et al. (1999).

Potential milk production estimates were calculated according to MILK2000 (Schwab et al., 2003). Milk per megagram DM and milk per hectare were calculated for corn and mixture forages. Values for ether extract were estimated from weighted values of corn silage (National Research Council, 2001) and lablab bean (Díaz et al., 2003) (depending on bean percentage in mixtures), while neutral detergent insoluble CP values were estimated from weighted values of corn silage and alfalfa (*Medicago sativa* L.) in the NRC tables (National Research Council, 2001).

Forage nutrient values were calculated with FEEDVAL4, a spreadsheet developed to assign a dollar value to feed ingredients (Howard and Shaver, 1997). The term *forage nutrient value* refers to the output of the spreadsheet, which allows the user to compare feeds based on current prices of feed ingredients and determine cost effectiveness. The FEEDVAL4 spreadsheet uses blood meal (undegradable intake protein, UIP), urea (degradable intake protein, DIP), shelled corn (energy), tallow (fat), dicalcium phosphate (phosphorus), and calcium carbonate (calcium) as reference feed ingredients. Prices for reference ingredients were based on April 2006 market values. The DM and CP components were measured values, while the total digestible nutrients of the mixtures were calculated using MILK2000. The UIP and DIP percentages of CP were estimated from a combination of corn silage and alfalfa values according to Linn et al. (1994), while the fat concentration was estimated from corn silage (National Research Council, 2001). Calcium and phosphorus concentrations for corn and beans were estimated from corn silage and alfalfa values from the NRC tables (National Research Council, 2001). Feed nutrient values were determined for 1 Mg of DM of each mixture and then multiplied by the corresponding mixture yield to provide crop value for 1 ha of each mixture.

Data from both years were pooled and analyzed as a randomized complete block design with the Windows version of SAS software package release 9.1 (SAS Institute, 2002). Tests concerning heterogeneity of variances were conducted to assess the appropriateness of pooling the data; however, no such problems existed in subsequent models. The MIXED procedure (SAS Institute, 2002) was used to detect treatment differences for the response variables of mixture yield, forage composition, milk per megagram and per hectare, and forage nutrient values. Corn density, bean planting date, and bean species were considered fixed effects, while years, locations, and blocks nested within locations were considered random effects. The Type 3 test of fixed effects was used to gauge significance at $P < 0.05$, and significant main effects were explored using the LSMEANS statement of SAS (SAS Institute, 2002). Fisher's protected LSD ($P = 0.05$) with no adjustment was used to compare mixture means, using the PDMIX800 macro (Saxton, 1998) when appropriate. Orthogonal contrast sets were also used to explore differences among significant ($P < 0.05$) interactions. The Pearson correlation coefficient, calculated in the CORR procedure (SAS Institute, 2002), was used to detect correlations between bean concentration in mixtures and mixture CP, NDF, IVTD, and starch concentrations.

RESULTS AND DISCUSSION

Environment and Crop Development

May 2004 was unusually cool and wet, delaying emergence and early seedling development of both corn and beans. Above-average precipitation occurred in May 2004 at both Arlington and Lancaster (Table 1). The weather in May 2005 provided drier environments at both locations. In 2005, Arlington received less-than-normal precipitation in June and early July, so the site was irrigated with 51 mm of water on 28 June, 11 July, and 19 July to supplement rainfall to near-normal levels.

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Early bean growth in both years was variable among the different bean species. Scarlet runner bean emerged first in the early bean planting date and quickly grew to the height of the corn plants at stage V3 (Ritchie et al., 1992) by early June. In 2004, velvet bean seedlings emerged later and took several weeks to reach a full stand due to cool, wet soil, similar to the observations of Tracy and Coe (1918). Lablab bean emergence was intermediate, but seedlings were not as vigorous as scarlet runner bean. In 2005, velvet bean and lablab bean seedlings developed similarly in the drier spring. Once the weather was warmer, velvet bean began to grow better; however, much of its biomass was attributed to stems rather than leaves. Both scarlet runner bean and velvet bean produced some pods, but day length was too long for flower production in lablab bean. Velvet bean produced more biomass than did lablab bean in 2005 (data not shown); in addition, corn lodged due to the weight of the velvet bean biomass before harvest in the velvet bean plots. The difference in velvet bean performance between years was associated with cool and wet spring conditions in 2004 compared with 2005 (Tracy and Coe, 1918).

Forage Yield and Nutritive Value

Mixture forage DM yields were affected by corn planting density and were 17.2 and 21.0 Mg ha^{-1} for low and normal corn densities, respectively (Table 2). The reduction in yield was associated with a 27,500 plants ha^{-1} difference between normal and low corn density treatments for which addition of beans did not compensate.

Table 1. Mean monthly precipitation and temperature at the Arlington and Lancaster Research Stations, WI, in 2004 and 2005 growing seasons.

	Arlington			Lancaster		
Month	Normal†	2004	2005	Normal	2004	2005
	Total monthly precipitation					
	mm					
Apr.	82	48	20	85	37	54
May	87	261	85	92	280	68
June	103	104	88‡	120	123	169
July	98	110	214‡	107	101	140
Aug.	108	72	78	117	92	106
Sept.	93	13	119	81	2	76
Oct.	62	83	15	61	69	12
Total	633	691	619	663	704	625
	Average monthly temperature					
	°C					
Apr.	8	9	10	8	9	11
May	15	13	12	15	14	13
June	20	18	22	20	19	22
July	22	21	23	22	20	22
Aug.	21	18	21	21	18	21
Sept.	16	18	19	16	18	19
Oct.	10	10	10	10	10	11
Avg.	16	15	17	16	15	17

†Normal precipitation and temperatures are based on 30-yr means.

‡Precipitation includes 51 and 102 mm of irrigation in June and July.

Mixture forage DM yields were also affected by the interaction of bean planting date and bean species. Planting date had no effect on lablab bean–corn mixture yields; however, the velvet bean mixture yielded 1.2 Mg ha^{-1} more ($P = 0.0011$) and the scarlet runner bean mixture yielded 0.89 Mg ha^{-1} more ($P = 0.0161$) in the late planting date compared with the early planting date (Fig. 1). In 2004, the early planted scarlet runner bean grew rapidly and became competitive with the corn plants early in the season but by harvest time contributed little because of potato leafhopper [*Empoasca fabae* (Harris)] and white mold [*Sclerotinia sclerotiorum* (Lib.) de Bary] damage. Lablab bean and velvet bean were not damaged by these pests. The later bean planting date did not have such a profound effect on yield because there was less early competition with corn. In 2005, the velvet bean mixture produced more with a late bean planting date because of greater bean biomass and corn lodging seen with the early bean planting date. In South Africa, Kaiser and Lesch (1977) reported a 7% DM yield reduction in a lablab bean–corn mixture compared with monoculture corn. Bryan and Materu (1987) did not find a significant difference between monoculture forage corn yield (8.8 Mg ha^{-1}) and a corn–cowpea mixture yield (9.4 Mg ha^{-1}) in West Virginia. Corn–bean mixture yields in the current Wisconsin experiments were approximately double those reported by Kaiser and Lesch (1977) and Bryan and Materu (1987), suggesting that environmental conditions were not optimal for corn production in the earlier experiments.

The corn component of mixture yields was reduced by bean inclusion in all mixtures (Table 2). Corn yield reductions ranged from 5.8% in mixtures with scarlet runner bean to 11.5% in velvet bean mixtures. The corn forage yields in the low and normal density treatments were 15.9 and 19.9 Mg ha^{-1}, respectively (Table 2). Cusicanqui and Lauer (1999) reported in Wisconsin that depending on location, as corn plant density increased from 44,500 to 104,500 plants ha^{-1}, corn forage yield increased by 1.7 to 4.1 Mg ha^{-1}.

Corn forage yields were affected by the interaction of bean planting date and bean species (Table 2). The velvet bean mixture yielded 1.4 Mg ha^{-1} more ($P = 0.0008$) and the scarlet runner bean mixture yielded 1.0 Mg ha^{-1} more ($P = 0.0168$) in the late planting date compared with the early planting date, whereas corn yield was not affected by bean planting date in mixtures with lablab bean (Fig. 2). The interaction of bean planting date and bean species occurred because early-planted scarlet runner bean grew rapidly in the early season and likely competed with corn for nutrients and light. Scarlet runner bean planted later did not have such a profound effect on corn forage yield.

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Table 2. Model significance levels, forage yield and nutritive value, and bean planting date and corn density effects of corn and bean mixtures pooled over four environments.

	Total yield	Corn yield	Bean in mix	CP†	NDF†	IVTD†	Starch	NDFd†	Milk per megagram	Milk per hectare
Source of variation						$P > F$				
Date	0.0023	0.0006	0.0389	NS‡	NS	NS	0.0333	NS	NS	0.0148
Density	<0.0001	<0.0001	<0.0001	<0.0001	0.0476	NS	0.0008	NS	NS	<0.0001
Date × density	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Species	0.0031	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0003	<0.0001	0.0002
Date × species	0.0346	0.0392	NS	NS	NS	NS	NS	NS	NS	NS
Density × species	NS	NS	0.0027	NS	NS	NS	NS	NS	NS	NS
Date × density × species	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
						Mixture effects				
Species	Mg ha^{-1}				g kg^{-1} DM			g kg^{-1} NDF	kg Mg^{-1}	kg ha^{-1}
Corn	19.1 ab§	19.1 a	0 c	61 c	372 b	833 a	388 a	551 a	1810 a	34700 a
Lablab bean mix	19.6 a	17.5 bc	114 a	69 b	383 a	827 b	364 b	549 a	1780 b	35000 a
Scarlet runner bean mix	19.0 b	18.0 b	52 b	64 c	367 b	835 a	385 a	550 a	1810 a	34300 a
Velvet bean mix	18.7 b	16.9 c	103 a	71 a	389 a	818 c	360 b	533 b	1740 c	32600 b
						Bean planting date and corn density effects				
Bean planting date										
Early	18.8 b	17.5 b	73 a	67	380	828	371 b	547	1790	33700 b
Late	19.4 a	18.2 a	62 b	66	375	829	378 a	544	1790	34700 a
Corn density										
Normal	21.0 a	19.9 a	54 b	63 b	375 b	828	380 a	543	1780	37400 a
Low	17.2 b	15.9 b	81 a	70 a	381 a	828	368 b	548	1790	30900 b

†CP, crude protein; NDF, neutral detergent fiber; IVTD, in vitro true digestibility; NDFd, neutral detergent fiber digestibility.

‡NS, not significant.

§Within columns, means followed by different letters are significantly different at $P < 0.05$.

In 2005, early-planted velvet bean was highly productive, and the large leaves shaded corn plants from the time of silking through harvest. In Zimbabwe, Maasdorp and Titterton (1997) reported that a corn–velvet bean mixture had a bean concentration of 294 g kg^{-1} and a corn biomass yield of 4.1 Mg ha^{-1}, which was only 50% of the corn DM yield without bean inclusion. Bryan and Materu (1987) reported that corn DM yield was reduced by 5 and 26% when corn was intercropped with cowpeas and climbing *P. vulgaris*, respectively.

Bean concentrations in mixtures were affected by bean planting date (Table 2). The early bean planting date treatment increased overall bean concentration from 62 to 73 g kg^{-1} DM (Table 2). An interaction of corn density and bean species for proportion of bean in mixtures was observed (Table 2). Corn density had no effect on the proportion of scarlet runner bean in mixtures; however, the lablab bean mixture contained 45 g kg^{-1} DM more ($P < 0.0001$) and the velvet bean mixture contained 48 g kg^{-1} DM more ($P < 0.0001$) in the low corn density treatment compared with the normal corn density treatment (Fig. 3). The greater proportion and total biomass of lablab bean and velvet bean in mixture with low density corn suggest that both beans take advantage of more light and less competition with reduced corn plant density. Low scarlet runner bean proportions in mixtures were caused by a combination of potato leafhopper and white mold damage in both years. Bryan and Materu (1987) found that a corn density of 64 600 plants ha^{-1} and a *P. vulgaris* density of 215,200 plants ha^{-1} led to a bean concentration of 170 g kg^{-1} DM. In Zimbabwe, Maasdorp and Titterton (1997) did not find substantial bean concentrations by sowing beans in the same row as the corn. For most

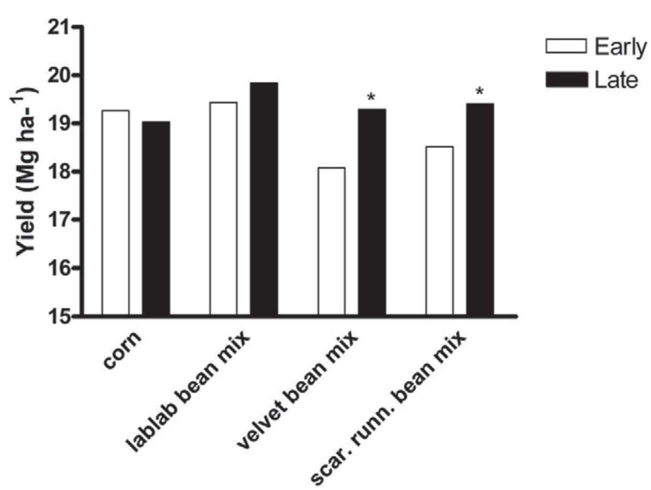

Figure 1. Effect of planting beans 2 (Early) or 4 (Late) wk after planting corn on mixture dry matter yield over four environments. Means are separated with orthogonal contrasts within each bean planting date and mixture. Pairs of bars with * are different at $P < 0.05$.

legumes tested (soybean, sunhemp [*Crotalaria juncea* L.], lablab bean, scarlet runner bean, cowpea), the proportion of legume was under 16% of total mixture biomass (Maasdorp and Titterton, 1997), and only the mixture with velvet bean approached 30%.

Crude protein concentration of pure fractions of lablab bean (130 g kg^{-1} DM), scarlet runner bean (150 g kg^{-1} DM), and velvet bean (140 g kg^{-1} DM) were all found to be significantly higher than CP concentration in monoculture corn (61 g kg^{-1} DM) (data not shown). Crude protein concentration was also greater in the lablab (69 g kg^{-1} DM) and velvet bean (71 g kg^{-1} DM) mixtures compared with monoculture corn (61 g kg^{-1} DM) (Table 2). Because of white mold and leafhopper damage, scarlet runner bean did not contribute enough bean forage to the mixtures to increase CP concentration over that of monoculture corn. The low corn density treatment contained more CP (7 g kg^{-1} DM) than the normal corn density treatment because of the greater proportion of bean in these mixtures (Table 2). The Pearson correlation coefficient for bean and CP concentration was $r = 0.54$ ($P < 0.0001$), suggesting a moderately positive linear relationship between the two variables (data not shown).

Kaiser and Lesch (1977) found that lablab bean increased CP concentration by 44% as corn density decreased from 72,000 to 18,000 plants ha^{-1}, with a constant lablab bean density of 108,000 plants ha^{-1}. Bryan and Materu (1987) reported that intercropping cowpeas and corn increased CP concentration by 9% and produced similar yields to monoculture corn.

Pure fractions of lablab bean (400 g kg^{-1} DM) and scarlet runner bean (440 g kg^{-1} DM) were found to be significantly higher in NDF concentration compared with monoculture corn (360 g kg^{-1} DM), while velvet bean (370 g kg^{-1} DM) was not different from corn (data not shown). Neutral detergent fiber concentrations tended to be greater in mixtures with greater bean proportions (Table 2). The NDF concentration in mixtures was affected by corn density and bean species (Table 2). The low corn density treatment contained more NDF (6 g kg^{-1} DM) than the normal corn density treatment. Lablab bean and velvet bean mixtures contained greater NDF concentrations than monoculture corn. Lablab bean and velvet bean mixtures had the highest proportion of bean, which increased NDF concentrations in the early bean planting treatment. The Pearson correlation coefficient for bean and NDF concentration was $r = 0.34$ ($P < 0.0001$), suggesting a moderately positive linear relationship between the two variables (data not shown).

Pure fractions of lablab bean (790 g kg^{-1} DM), scarlet runner bean (760 g kg^{-1} DM), and velvet bean (810 g kg^{-1} DM) were all found to be significantly lower in IVTD concentration compared with monoculture corn (830 g kg^{-1} DM) (data not shown). In vitro true digestibility of monoculture corn and mixtures was high, varied little among treatments, but decreased slightly as proportions of bean in mixtures increased (Table 2). The IVTD concentration was affected by bean species; only the lablab bean (827 g kg^{-1} DM) and velvet bean (818 g kg^{-1} DM) mixtures were lower than monoculture corn (833 g kg^{-1} DM). Since these mixtures also contained the highest bean concentrations, IVTD concentrations were reduced accordingly. The Pearson correlation coefficient for bean and IVTD concentration was $r = -0.30$ ($P < 0.0001$), suggesting a moderately negative linear relationship between the two variables (data not shown).

Neutral detergent fiber digestibility, which ranged from 533 to 551 g kg^{-1} NDF, was affected little by bean or management treatments (Table 2). The velvet bean–corn mixture had lower NDFd than other mixtures or

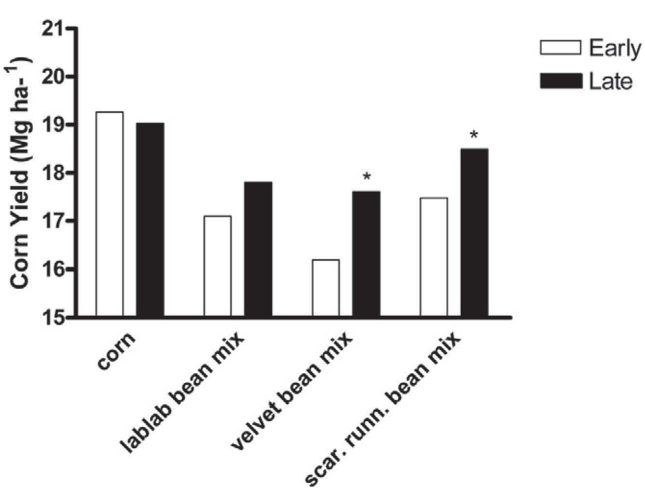

Figure 2. Effect of planting beans 2 (Early) or 4 (Late) wk after planting corn on corn dry matter yield over four environments. Means are separated with orthogonal contrasts within each bean planting date and mixture. Pairs of bars with * are different at $P < 0.05$.

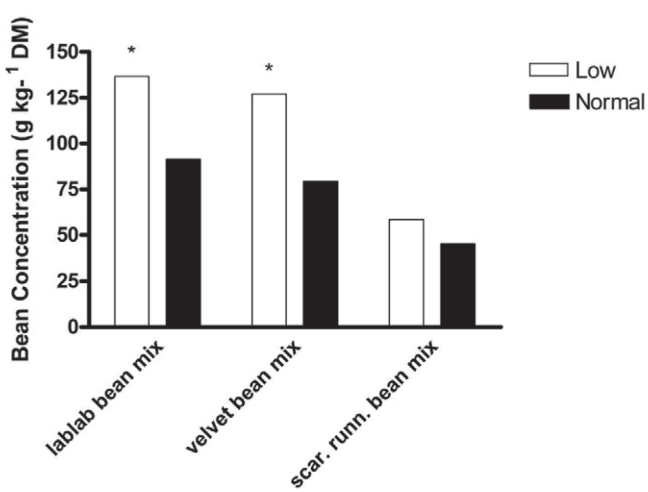

Figure 3. Effect of planting corn at a density of 82,500 plants ha^{-1} (normal) or a density of 55,000 plants ha^{-1} (low) on bean concentration in mixtures over four environments. Means are separated with orthogonal contrasts within each corn density and mixture. Pairs of bars with * are different at $P < 0.05$.

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monoculture corn (Table 2). Generally, NDFd is greater for grasses than for legumes (National Research Council, 2001), but the magnitude of this difference and the proportions of legume in these mixtures were not great enough to have a significant effect on the mixtures.

Starch concentration, primarily driven by the amount of corn grain in mixtures, was affected by bean planting date, corn density, and bean species (Table 2). The late bean planting date contained 7 g kg^{-1} DM more starch than the early bean planting date. The normal corn density treatment contained 12 g kg^{-1} DM more starch than the low corn density treatment. Starch concentrations were greatest in monoculture corn and the scarlet runner mixture, both of which contained a lower proportion of bean compared with the other two mixtures (Table 2).

The data suggest that as bean concentration in mixtures is increased, starch concentrations decline. Starch concentration in vegetative legume forage is much lower than in corn, often ranging from 2 to 48 g kg^{-1} DM in fresh alfalfa depending on cutting time (Owens et al., 1999). The lower starch concentration in corn–bean mixtures could also be associated with grain yield loss caused by competition with the beans for light and other resources (Ngouajio et al., 1999). The Pearson correlation coefficient for bean and starch concentration was $r = -0.53$ ($P < 0.0001$), suggesting a moderately negative linear relationship between the two variables (data not shown).

Calculated milk per megagram forage is an estimate of milk production that can be attributed to that forage fed in a total mixed ration, calculated from the MILK2000 spreadsheet (Schwab et al., 2003). Calculated milk per megagram forage was affected by bean species (Table 2). The velvet bean mixture was significantly lower than the other mixtures, with a calculated milk per megagram forage of 1740 kg Mg^{-1} (Table 2). The scarlet runner bean mixture, although not different from monoculture corn, produced the highest milk per megagram forage at 1810 kg Mg^{-1} (Table 2). Cox and Cherney (2005) reported 1692 kg milk Mg^{-1} forage, averaged over three corn hybrids in New York. The corn hybrids reported by Cox and Cherney (2005) had higher NDF and lower starch values compared with the current research, resulting in lower calculated milk production.

Calculated milk per hectare integrates forage nutritive value and yield through the MILK2000 spreadsheet (Schwab et al., 2003). Calculated milk per hectare was affected by bean planting date, corn density, and bean species (Table 2). The late bean planting date treatment produced 1000 kg ha^{-1} more calculated milk per hectare compared with the early bean planting date treatment (Table 2). The normal corn density treatment produced 6500 kg ha^{-1} more calculated milk per hectare compared with the low corn density treatment (Table 2). The velvet bean mixture was lower in calculated milk per hectare (32,600 kg ha^{-1}) compared with all other mixtures or monoculture corn (Table 2). The lablab bean mixture, although not significantly different from monoculture corn or the scarlet runner bean mixture, had the highest calculated milk per hectare, at 35,000 kg ha^{-1} (Table 2).

The normal corn density treatment produced more calculated milk per hectare because more forage was harvested compared with the low corn density treatment plots. In addition, the early bean planting date treatment had a higher bean percentage and thus a reduced corn yield and subsequently lower calculated milk per hectare. Velvet bean reduced mixture forage yield in 2005 and subsequently reduced calculated milk per hectare. Because calculated milk per hectare is a variable related to forage yield and nutritive value, any reduction in either reduces the values of calculated milk per hectare. Cox and Cherney (2005) reported 25,700 kg calculated milk ha^{-1} averaged over three corn hybrids. Average DM yields for the same hybrids was 14.9 Mg ha^{-1} (Cox and Cherney, 2005), approximately 25% lower than in the current research.

The lablab bean mixture had slightly higher yield (not significant at $P < 0.05$) but also a slightly higher NDF concentration than monoculture corn. The yield- and energy-based MILK2000 model reveals no advantage to growing lablab bean with corn for forage. Because the model does not take into account the added value of additional CP in the ration, FEEDVAL4, a model that considers the value of feed ingredients (Howard and Shaver, 1997) was used to evaluate corn–bean mixtures.

The feed nutrient value was greater in the corn–bean mixtures compared with monoculture corn. Only the lablab bean mixture, however, increased crop value over monoculture corn (Table 3). The feed nutrient value, based on value of feed ingredients, was greatest for the lablab bean and velvet bean mixtures (\$80 Mg^{-1} DM) (Table 3). These values were greater than the other mixtures primarily because of a higher CP concentration in the two mixtures. When the feed nutrient value is multiplied by the total DM yield on a land basis, an estimated value can be given to a crop. The crop value of the mixtures per hectare was the greatest for the lablab bean mixture (\$1570 ha^{-1}) (Table 3) because of high feed nutrient value and high yield. While the velvet bean mixture had a high

Table 3. Calculated forage nutrient value of corn–bean mixtures pooled over four environments.†

Mixtures	Feed nutrient value	Crop value
	\$ Mg^{-1} DM	\$ ha^{-1}
Corn	77 c‡	1480 b
Lablab bean mix	80 a	1570 a
Scarlet runner bean mix	79 b	1490 b
Velvet bean mix	80 a	1500 b

†Within columns, values are averaged across treatment levels.

‡Within columns, means followed by different letters are significantly different at $P < 0.05$.

feed nutrient value (dollar per megagram DM), total mixture yield was relatively low and thus it was not worth as much per hectare. FEEDVAL4 estimates the value of feeds based on the price of different nutrients with CP being a major contributor. So, both feed nutrient value (dollar per megagram DM) and crop value (dollar per hectare) will change with market price for feed ingredients. The lablab bean mixture was the most promising because of additional value associated with higher CP concentration along with no reduction in total DM yield compared with monoculture corn.

CONCLUSIONS

While CP concentration was increased in lablab bean– and velvet bean–corn mixtures, fiber and digestibility were compromised compared with monoculture corn. Increased bean concentration in the velvet bean mixture negatively affected calculated milk production per megagram forage (70 kg Mg^{-1} less) and milk per hectare (2100 kg ha^{-1} less). In contrast, the lablab bean mixture was not different from monoculture corn in terms of calculated milk per hectare. Lablab bean proved to have the best potential as an intercrop with corn in these experiments. Yield of the lablab bean mixture was not different from monoculture corn and had a calculated feed nutrient value higher than monoculture corn. These experiments show that lablab bean grown with corn has the greatest potential of the three beans to increase CP concentration above monoculture corn without compromising forage yield or calculated milk hectare and potentially increasing crop value (dollar per hectare) in the northern United States. On the basis of this study, the additional costs connected with bean seeds, machinery, and labor costs associated with a separate operation must be less than \$90 ha^{-1} for the lablab bean mixture to be a profitable alternative to monoculture corn.

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