AN EVALUATION OF CORN YIELD, INTERCROP GROWTH AND SOIL NITROGEN LEVELS IN SILAGE AND GRAIN CORN INTERCROP SYSTEMS

by

Margaret E. Hope-Simpson

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ABSTRACT

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AN EVALUATION OF CORN YIELD, INTERCROP GROWTH AND SOIL N LEVELS IN SILAGE AND GRAIN CORN INTERCROP SYSTEMS

The objectives of this study were to evaluate the effects of earlier corn (*Zea mays* L.) harvest, on corn yield, intercrop growth, and soil N levels, and to evaluate the effects of red clover (*Trifolium pratense* L.) compared to ryegrass (*Lolium multiflorum* Lam.) as intercrops on corn yield and soil N levels.

After two years, earlier corn harvest did not result in greater intercrop growth or higher soil N levels compared with later corn harvest and there was no significant soil N contribution by legume intercrops in either harvest period. Thus, no soil N benefit was found from using intercrops in early harvest for silage compared tolater harvest for grain corn, nor from using red clover compared to ryegrass as an intercrop.

In the early harvested silage system, a quadratic corn yield response to added N suggested that near-maximum corn dry matter yields were obtained at the rate of 140 kg N ha^{-1}. Maximum total dry matter yields were not obtained in the late harvest grain system in any site-year. Legume and non-legume intercrop species had similar effects on corn yield.

RESUME

M.Sc. Margaret E. Hope-Simpson Ressources Renouvelables

EVALUATION DES RENDEMENTS EN MAIS, DE LA CROISSANCE DES CULTURES INTERCALAIRES ET DE LA TENEUR EN AZOTE DES SOLS DANS DES SYSTEMES DE CULTURE INTERCALAIRE MAIS-ENSILAGE ET DU MAIS-GRAIN

Le but de l'étude était de comparer les effets d'une rècolte hâtive de maıs-ensilage (Zea mays L.) sur les rendements, la croissance des cultures intercalaires et la teneur en azote des sols, par rapport à la culture du maıs-grain. On a aussi comparé les effets des cultures intercalaires du trèfle rouge (Trifolium pratense L.) et du lolium annuel (Lolium multiflorum Lam.) sur les rendements en maıs et sur la teneur en azote des sols.

Après deux ans, la croissance des cultures intercalaires et la teneur en azote des sols du maıs-ensilage n'étaient pas plus élevées que pour le maıs-grain. De même, les cultures intercalaires de légumineuses n'ont pas augmenté la teneur en azote des sols de l'un ou l'autre des systèmes.

Dans le système maıs-ensilage, le rendement quadratique en matière sèche, en réponse au taux d'azote présent, suggère des rendements près des taux maximums. Des rendements maximums en matière sèche pour le maıs-grain n'ont pas été observés au cours de l'étude. Les différents types d'espèces utilisées pour les cultures intercalaires n'ont eu que peu d'effets sur les rendements en maıs et une forte compétition pour l'azote et l'eau fût observée entre le mais et les cultures intercalaires, qu'elles soient de type légumineuse ou non.

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INTRODUCTION

With an unsurpassed yield potential and concentration of total digestible nutrient, corn (Zea mays L.) continues to be one of the most important high energy livestock feeds in Canada (Statistics Canada 1989). The majority of Canadian corn production occurs in Ontario and Quebec, where 211 and 944 thousand hectares of silage and grain corn respectively, are grown. This area accounts for 73 % of all silage and 96 % of all grain corn grown in Canada (Statistics Canada 1986).

The detrimental effects of corn production on soils are well documented. In particular, continuous corn grown for silage, with its low residue return, intensive cultivation and high fertilizer input, can result in degradation of soil structure and nitrate (NO_3^-) pollution of ground water. Reduced soil productivity leads to a decline in yields over time, and studies by Martel and MacKenzie (1980), Strickling (1975), and Richards et al. (1983) have shown grain yield reductions from 8-74 % (depending on soil type), resulting from long-term continuous cultivation of corn. These yield reductions were attributed to a depletion of soil organic matter, decreased structural stability and increased soil compaction resulting from the lack of residue addition and intensive cultivation.

While the benefits of crop rotation are numerous, increasing pressure to maximize the economic return from good arable land has discouraged its widespread adoption by Quebec farmers. Recent studies in both Quebec and in Ontario (Tomar et al. 1988; Nanni and Baldwin 1987; Samson and Coulman 1989; Claude 1990) have shown that intercropping corn with legumes and other forages improved soil physical properties and tilth. These improvements in soil quality however, were mostly at the expense of corn yield. Corn yield reductions were largely due to nitrogen (N) deficiency and water deficits in intercropped plots, resulting from intercrop competition for soil and fertilizer N and soil water.

Proposed methods of reducing intercrop effects on corn yield include late intercrop seeding and increased corn populations. The earlier harvest of corn in silage production compared with grain, provides a late-season period of intercrop growth free from competition with corn. Few studies, however, have compared the use of intercrops in silage and grain corn systems with respect to the intercrop effect on corn yield, soil N level and soil quality.

The objective of this research was to evaluate earlier corn harvest in the silage system compared with grain, with respect to corn dry matter yields, intercrop growth, and soil N levels.

In describing the above research, the thesis consists of four chapters: a review of the literature, description of experimental materials and methods, presentation of experimental results, and a discussion of the results. At the end of the thesis are the general conclusions, and some suggestions for future work.

CHAPTER ONE

LITERATURE REVIEW

1.1 Intercrops in Corn Production

Intercropping is the growing of two or more crops simultaneously in the same area. Crops are not necessarily sown or harvested at the same time, and the objectives for growing the intercrop range from increasing yield efficiency, to providing livestock feed or a green manure or cover crop for soil enrichment and conservation. Intercropping has been practised for centuries in low-input agroecosystems (i.e., in Africa, Asia and Latin America) as a means to increase productivity (Allen and Obura 1983). More recently in North America, intercropping cereals (mainly corn and sorghum) with legumes and other forages is being considered as a possible way to maintain high productivity while improving the fertility and structural quality of soils.

Intercropping literature includes a number of related cropping system terms (ie., "companion crop", "interseed", "undercrop", "cover crop", and "green manure"). The use of these terms is intended to indicate the variety of possible temporal and spatial relationships between the component crops of an intercrop system. In the present study, the term "intercropping" will refer to the practice of growing legumes or other forage species between the rows of corn. Intercrops may be seeded at the same time as corn or late-seeded when corn is 15-30 cm high, and are either plowed down as green-manure in the fall or allowed to over-winter as a cover-crop, to be incorporated the following spring prior to corn seeding.

In the southeastern U.S., Pacific coastal plains and north to the midwest, intercropping corn with legumes and other forages has been used successfully to increase corn yields and soil productivity by adding biologically fixed N and organic matter. In some cases, corn yield increases of 10-30 % (Ebelhar et al. 1984; Herbek et al. 1987; Decker et al. 1987) and soil N gains of 90-200 kg/ha (Ebelhar et al. 1984; Flannery 1981) have been obtained when fall-seeded legumes are grown as winter covers in continuous no-till corn.

In more northern latitudes, however, a shorter growing season means both a lower potential for legume N-fixation and a greater proportion of time in which the corn and intercrop are simultaneous. In this situation, intensified corn-intercrop competition for all growth resources has resulted in significant corn yield reductions. Corn grain yields were reduced by up to 33% and silage yield reduced from 17-47% by alfalfa (Medicago sativa L.) interseeded at the time of corn establishment in Nebraska and Illinois (Nordquist and Wicks 1974; Jackobs and Gosset 1956). In Quebec, a 20% corn yield depression was found at all rates of applied N when intercrops were seeded at the same time as corn (Tomar et al. 1988). Both Nanni and Baldwin (1987) in Ontario and Scott et al. (1987) in New York State, reported substantial contributions of dry matter and N from intercrops, but no yield benefit to corn. Kurtz (1952) suggested that competition in corn-intercrop systems is essentially competition for N and water, and that when both of these are in sufficient supply, high corn yields can be obtained despite fairly luxuriant growth of the intercrops. In Quebec, a linear corn-yield response to applied N in intercrop plots suggested that N was present at a sub-optimal level (Tomar et al. 1988). That water was also often limiting, is suggested by the lack of a yield depression on some soils in years with high precipitation.

1.2 Management Factors Affecting Corn Yield, Intercrop Growth and Soil N

Efforts to eliminate the corn yield depression associated with intercropping have involved manipulating one or more of the management factors that influence the intensity of corn-intercrop competition. These factors have included intercrop seeding date, intercrop species selection, corn plant population and level of N fertilization.

One factor that has received little attention is corn system, or corn harvest date. Previous intercropping studies have not evaluated the impact of the earlier harvest of corn in silage production compared with grain, on corn-intercrop competition for soil N or water. The effect of intercrops on levels of soil organic C and N in the two corn systems, is also largely unknown. Furthermore, no comparisons have been made of the performance (ie., contributions of dry matter and N) of different species of intercrops under the two corn systems. Brief consideration will therefore be given to the effect of intercrop species on corn yield and soil N, and the effect of corn systems on soil organic carbon (C), N and growth of intercrops.

1.2.1 Effect of Intercrop Species on Corn Yield and Soil N

In rotational cropping schemes, perennial forage legumes (ie. alfalfa, clovers) provide large amounts of residual N to subsequent crops. For example, Triplett et al. (1979) in Ohio found that 2-3 year old alfalfa stands supplied nearly all (up to 170 kg N/ha) of the N needed for subsequent corn crops. North of latitude 37° N (or where the growing season is less than 200 days and precipitation is less than 75 cm/year), however, there are few reports of adequate N contributions from these legumes when grown as intercrops (Papendick et al. 1976). When alfalfa was band-seeded into continuous corn, corn yields were 9 % lower than equally fertilized monocrop corn and 18% lower than corn yields in the corn-wheat-alfalfa rotation (Triplett 1979). In New York State, no significant corn yield response resulted from using intercrops, despite N contributions of 80, 20 and 40 kg N/ha from red clover (*Trifolium pratense* L.), alfalfa and perennial ryegrass (*Lolium perenne* L.), respectively (Scott et al. 1987). The authors suggest 56 kg N/ha as the minimum intercrop contribution of N required to elicit a significant corn yield response. That no corn yield response occurred from any intercrop treatment was explained by the suggestion that only 50% of legume N would be available to a subsequent corn crop; the best treatment (red clover) therefore only provided 40 kg available N.

In the absence of a N benefit to corn from legumes, grass intercrops have advantages. More N fertilizer, however, may be required. Annual and perennial grasses, with their high dry matter production and extensive root systems, may have a higher capacity than legumes for weed suppression, soil improvement, and interception of residual NO_3-N (Scott and Burt 1985; Kunelius and Goit 1982; Samson and Coulman 1989). In New York State, ryegrass intercrops produced the greatest amount of ground cover and more dry matter than either red clover or alfalfa. Dry matter yields of the intercrops prior to plowdown (average of 4 years of data) were 2.08, 1.09, 3.18 and 2.24 t/ha for red clover, alfalfa, annual ryegrass (Lolium multiflorum Lam.), and rye (Secale cereale L.), respectively (Scott et al. 1984). Sampson and Coulman (1989) noted advantages of ryegrass over red clover in weed control with corn grown in Ontario. In Quebec, late-seeded ryegrass intercrops allowed greater flexibility in the use of both tillage and herbicides, and repressed weeds more effectively than either early seeded or legume intercrops (Claude 1990). Groffman et al. (1987) noted higher losses of NO_3-N by leaching and denitrification under clover compared to ryegrass plots. Leaching losses of NO_3-N were 1.95-2.04 mg/l under clover compared to 0.26-0.50 mg/l under ryegrass. The ability of ryegrass to intercept and recycle NO_3-N can be exploited to enhance fertilizer N recovery in corn production (MacKenzie 1990). Intercrops could allow soil N levels to be maintained for optimum corn production during the summer, while reducing the hazards of N loss under high N at the end of the season.

1.2.2 Effect of Corn Systems on Soil C, N and Growth of Intercrops

1.2.2.1 Effect of Corn Systems on Soil C and N

Studies measuring soil organic C and N changes under different cropping systems, established that systems containing corn had 10% more Walkley-Black carbon (WBC) and 7% more total Kjeldahl nitrogen (TKN) than systems that did not contain corn. The quantity of residue returned was the major factor affecting WBC and TKN (Zielke and Christenson 1986). Despite a high potential for dry matter production with corn, the evidence for soil C and N levels being maintained adequately is inconclusive. Several studies have evaluated the effect of fall-incorporated corn stover residues on the level of soil organic C and N. In certain cases, stover residues increased both soil organic C and total N (Morachan et al. 1972; Sanford 1968) whereas in others, both organic matter and total N declined despite annual additions of stover (Ketcheson and Beauchamp 1978).

Corn stover residues generally remain on the soil surface when corn is harvested for grain but are largely removed when the crop is harvested for silage. The potential for loss of organic C and N in continuous corn soils is therefore more extensive and severe under silage than under grain corn systems (Barnhart et al. 1978). Obviously, the potential benefits to soil quality from increasing crop residues in this system, are also greater than in the grain system.

The amount of crop residues required to maintain soil C and N in rotations with corn has been estimated to be 6-7 Mg/ha/year (Larson et al. 1974; Cope et al. 1958; Liang et al. 1989). The amount of residue generated by a given system depends on the type of crops grown, the latitude where grown, and the level of N fertilizer applied during the growing season. Cover crops and green manures have been used to increase soil organic matter and N in grain corn systems with mixed success. Both organic matter and soil N were increased after only one year of cover crops in no-till corn in Kentucky (Frye and Blevins 1989), whereas there was no effect on organic matter and N from four years of cover crops in corn on the coastal plains (McVicker et al. 1946). Poyser et al. (1957) in Manitoba report a decrease of 27.9% in organic C and 15.9% in N over 25 years, despite inclusion of green manure crops in a wheat-corn-wheat rotation.

1.2.2.2 Effect of Corn Systems on Growth of Intercrops

In Quebec, corn is harvested in early to mid September for silage, but in mid- to late October for grain. The silage system may offer an intercropping advantage by virtue of this competition-free period that follows the harvest of corn for silage. Previous intercropping literature, however, does not contain comparisons of silage and grain corn systems with respect to the organic matter and soil organic and inorganic N contributions of intercrops.

Early removal of corn in silage production in Nebraska, permitted excellent fall growth of alfalfa under irrigated conditions (Nordquist and Wicks 1974). The effect of such a late-season period on intercrop growth in a shorter season region such as Quebec is largely unknown. It may be speculated however, that a greater amount of intercrop biomass and legume activity could result. Greater intercrop growth in the silage system could presumably result in a greater contribution to the pool of either soil organic C or organic or inorganic N in that system compared to the grain system.

1.3 Hypotheses

Based on the assumption that the earlier harvest of corn in silage production compared with grain provides a late-season period of intercrop growth that is free from competition with corn, the following hypotheses are proposed:

1. Reduced corn-intercrop competition in silage production results in greater intercrop biomass.

2. Reduced corn-intercrop competition in silage production results in higher soil N levels (fall and/or spring).

3. There is an optimum level of N fertilization in corn-intercrop systems, that maximizes corn yields while optimizing the N and dry matter contribution of intercrops.

CHAPTER TWO

MATERIALS AND METHODS

2.1 Soil and Precipitation

The experiment was conducted in southwestern Quebec from 1988 to 1989 at two sites of contrasting soil types (Table 2.1). The soils were a Chicot sandy loam (Grey-Brown Luvisol) and a Ste.Rosalie clay (Humic Gleysol), located at the Emkikl A. Lods Agronomy Research Centre, Macdonald Campus, Ste. Anne de Bellevue and on Ile Perrot, respectively. These soils have been described by Lajoie and Baril (1956). Previous cropping histories were continuous cultivation of cereals and annual row crops at the Chicot site and 15 years under pasture at the Ste. Rosalie site.

Table 2.1 Some characteristics of the Chicot and Ste. Rosalie soils (based on samples taken from the 0-20 cm depth in 1988).

Soil series	Organic carbon	Total N	Particle size distribution Clay	Silt	Sand	Texture	pH (1:1,soil: H_2O)[z]
	%						
Chicot	2.17	0.15	22	21	57	sandy loam	6.5
Ste. Rosalie	3.12	0.20	33	47	20	clay	5.5[y]

[z]Method of pH measurement is presented in section 2.5
[y]The soil pH of samples taken in August 1989 at the Ste. Rosalie site was 6.1, as a result of the May 1989 application of limestone.

Years were similar in terms of total precipitation during the growing season. In both years and at both sites, precipitation during the critical month of July was below the 30-year average for this region (Table 2.2).

Table 2.2 Monthly precipitation during the 1988 and 1989 growing seasons at the two sites, and the 30 year average for the region[a].

	Chicot site		Ste. Rosalie site		30 year ave.
	1988	1989	1988	1989	
Month	(mm)	(mm)	(mm)	(mm)	(mm)
May	47	84	38	92	78
June	75	100	89	100	37
July	37	37	23	26	95
August	113	94	134	64	112
September	58	60	88	57	85
October	33	26	44	100	34
Total	360	393	416	439	441

[a]Data from Ste. Anne de Bellevue weather station

2.2 Site Establishment

Experimental Layout

At each site, corn yield, intercrop growth and soil N levels were evaluated in two corn production systems (silage and grain), at three levels of N fertilization (0, 70, and 140 kg N/ha), and with two intercrop species, red clover (Trifolium pratense L.'Florex') and ryegrass (Lolium multiflorum Lam.'Lemtal'). Treatments were arranged in a split-plot design with four replicates. In each replicate, corn production systems were main plots (18 m x 5 m) and the six N-intercrop combinations were sub-plots (3 m x 5 m) within each main plot.

Soil Preparation

In May 1988 at the Ste. Rosalie site, and each fall at both sites, soil was plowed with a conventional two-bottom moldboard plow (Kongskilde) to a depth of 20 cm. Secondary cultivation in the spring consisted of two passes of a Massey Ferguson tandem-disk harrow to a depth of 10 cm followed by one pass of a vibrashank ("Triple-K") harrow (Kongskilde).

Seeding

The corn hybrid DeKalb 362 was seeded using a 4-row planter (model SP510; Gaspardo). In both corn systems, plots were seeded at a rate of about 100,000 seeds per hectare and later thinned to 70,000 when corn was at a three to four leaf growth stage. Intercrops were seeded at the time of corn planting, by broadcasting either red clover or ryegrass seed on either side of the middle two corn rows of each plot. Thus, each plot contained four rows of corn and three rows of intercrop. Plots were seeded on May 24 in 1988, and on May 15 and 16 in 1989.

Fertilization and Liming

Nitrogen (urea) fertilizer treatments and potassium (300 kg of K_2O/ha as muriate of potash) were broadcast by hand, after discing and before planting. Phosphorus (140 kg P_2O_5/ha as triple super phosphate) was banded 5 cm below and beside corn seed at planting. The Ste. Rosalie site was limed in May, 1989 to obtain a pH of 6.5.[1] Commercial limestone was applied to the whole field with a custom lime-spreader, and soil incorporated with a chisel plow and disk harrow. Rates of liming material were based on laboratory determination of soil water and buffer pH (method given in section 2.5) of urface (0-20 cm) samples taken in early May, 1989.

[1]The pH of surface (0-20 cm) samples taken at this site in August 1989 was 6.1.

2.3 Site Management

Weed Control

The pre-plant incorporated herbicide Eradicane (S-ethyldipropylcarbamothioate; ICI Chipman, Longeuil, Que.) was applied to red clover plots to control germinating annual grasses. The herbicide was applied at the rate of 5.0 L/ha (800 g/L (a.i.)). Immediately following application, the Eradicane was soil incorporated with a vibrashank ("Triple-K") harrow. No herbicide was used on ryegrass plots in 1988. In 1989, the pre-emergence herbicide Dicamba (3,6-dichloro-2-methoxy benzoic acid; Sandoz Agro Canada Inc., Mississauga, Ont.) was applied to ryegrass to control annual and perennial broadleaf weeds. Dicamba was applied at the rate of 0.25 L/ha (480 g/L (a.i.)) (Humburg, 1989). In addition to using herbicides, two sessions of hand-hoeing were performed in all plots at the Chicot site between June and July of 1989.

Pest Control

In 1988, 0.75 g per linear meter (0.15 g/m (a.i.)) of Terbufos ((5-)tert-butylthio) methyl o-o-diethyl phosphoro dithioate; Cyanamid of Canada, Baie d'Urfe, Que.) was soil applied to corn at seeding time to prevent corn root worm (*Diabrotica barberi*, Smith and Laurence) damage. No insecticide was applied at seeding in 1989. In early August of 1989, Furadan 480F (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate; Pfizer Canada Inc., Kirkland, Que.) was applied to corn at the rate of 1.1 L/ha (480 g/L (a.i.)) to control European corn borer (*Ostrinia nubialis*, HBN.)

2.4 Harvesting and Sampling

Corn Harvesting

Silage corn was harvested in the first week of September, and grain corn in the second week of October. Whole-plant silage, stover and grain were sampled for yield and nutrient content. In silage plots, the two center rows of corn were harvested with a tractor mounted silage harvester. Chopped silage was collected, weighed, and a subsample (approximately 0.5 kg) removed for moisture determination and nutrient analysis. Silage yields at 0% moisture content were determined by oven-drying at 70° C for 2-3 days. In grain plots, the ears of the two center rows were hand-picked. The number of ears harvested was noted as well as the number of plants. The ears were weighed and a subsample of eight ears weighed for shelling. Corn was shelled with a manual SCS-1 corn sheller (Agriculex) and humid kernels were weighed, dried for 4 days at 70° C, and reweighed for dry matter and moisture determination. Corn stover was harvested and subsampled in the same manner as silage, except that the excess stover was returned to the plot. After harvesting for stover and grain yield, all ears were removed and the stover remaining in the field was chopped and plowed down in late October. Corn N-uptake and dry matter yields were reported for both above-ground total dry matter (both corn systems), and grain and stover dry matter (grain system only).

Intercrop Biomass Sampling

Intercrop and weed biomass were determined in each plot just prior to grain harvest. Biomass sampling involved selecting 4 locations at random within the plot and placing a quadrat (0.25 m^2) in the center of the location. All vegetation inside the quadrat was cut to 2.0 cm above soil, and either brought immediately to the lab for sorting, or stored at 1° C until sorting. Vegetation was sorted as to either "weed" or "intercrop", placed in paper bags, dried for 2 days at 70° C, and weighed. The above-ground dry matter yield of each component (weed, intercrop), and their relative contribution to the total biomass (weed plus intercrop), was then determined (Ghafar and Watson 1983; Topham and Lawson 1982).

Soil Sampling

For the determination of soil inorganic N (NO_3-N and NH_4-N), soils were sampled in the spring prior to fertilizer application and in the fall after harvesting using a tractor-mounted soil sampler. One 10 x 60 cm soil core was taken from the center of each plot and separated into 20 cm increments to obtain three sampling depths (0-20, 20-40, and 40-60 cm). Each depth increment of soil was thoroughly mixed to obtain a composite subsample. Samples were either brought immediately to the lab for analysis or stored at 1° C until extracted.

Soil total N and organic C was determined using surface (0-20 cm) soil samples taken in May 1988 and in August 1989. The May 1988 samples were those of the 0-20 cm depth obtained for determination of soil inorganic N. The August 1989 samples were obtained using a manual soil auger. Three soil cores taken at random from each plot were bulked, mixed, and subsampled. Soil samples were dried at 105° C and ground to pass a 2 mm sieve prior to laboratory analysis.

Soil bulk density was determined using a Troxler 3401 nuclear density gauge for the 0-20 cm depth, and by taking 10 x 20 cm soil cores for 20-40 and 40-60 cm depths.

2.5 Laboratory Analyses

Laboratory analysis for soil NO_3-N and NH_4-N involved extracting moist soils (15-20 g) with 100 ml 1M KCl, and analyzing filtrates colorimetrically on a Technicon Auto-Analyzer (Keeney and Nelson 1982). Copper was used to reduce NO_3-N to NO_2-N, which was subsequently determined by the Griess-Ilosvay procedure (Kamphake et al. 1967). Ammonium was determined using the indophenol blue procedure (O'Brian and Fiore 1962). Moisture determinations made at this time were used to correct for the amount of soil solution present in exc ss of the added 100 ml 1M KCl. The concentration of NO_3-N and NH_4-N in the soil was converted to total NO_3-N and NH_4-N (in kg N/ha) by multiplying values (in ug N/ g soil) by the volume of soil in 1 hectare (2.0×10^3 m^3/ha) and the mean values of soil bulk density for each depth. These values for NH_4-N and NO_3-N were summed, and the total reported as soil inorganic N. Soil total N was determined by the Kjeldahl method described by Bremner (1965), and soil organic C was determined by the Walkley-Black procedure (Allison 1965). Soil water and buffer pH were determined in a 1:1 soil/water or soil/buffer ratio using a glass-calomel electrode (Peech 1965; Woodruff 1948).

2.6 Data analyses

2.6.1 Statistical Analysis

Statistical analysis consisted of analysis of variance with single degree of freedom comparisons, performed using the Statistical Analysis System (Barr et al. 1979). For certain comparisons, least significant difference values were used to locate differences among means (Steel and Torie 1980). To estimate effects of corn systems, intercrop species, and N fertilization on soil total N and organic C, covariance methods (using initial values as the independent variable) were used (Liang 1989). Due to a high amount of variability in N-recovery estimates, and because variances were in some cases proportional to the means, a log-transformation (log (N-recovery + 1)) was performed on the data prior to statistical analysis.

2.6.2 Crop Residues

The amount of soil incorporated crop residues produced by each corn system-intercrop species combination, was determined by adding the amount of residues produced by either corn and/or intercrops that was to be plowed down in the fall. Crop residues from corn consisted of the stover residues produced by the grain system. Residues from intercrops were comprised of the biomass of seeded intercrops and weeds.

2.6.3 N-Recovery Based on Fertilizer N Applied[2]

N-Recovery in Corn, Intercrops, and Soil and Unaccounted for N

The percentage of N recovered in corn (total above-ground dry matter), intercrops (seeded intercrops plus weeds), and soil, expressed as a percentage of the amount of N applied, was determined by the difference method (Allison 1966). Recoveries were established by subtracting corn N-uptake, intercrop N-uptake, or soil inorganic N values of zero-N treatments, from the corresponding values for fertilized treatments. The difference of these values was divided by the rate of N applied, and expressed as a percentage. The amount of unaccounted for N was determined from the difference between 100 % and the summed percentages of the N-recoveries. N-recovery of intercrops was only determined in 1989.

N Balance Sheet for Corn-Intercrop Systems

Data for the uptake of N by harvested corn, crop residues, and fall soil inorganic N was used to construct a N balance sheet, to indicate the amount of N removed from and retained by each corn-intercrop system in 1989[3]. In the N balance sheet:

N removed = N taken up by harvested corn

and

N retained = fall soil inorganic N + N taken up by soil-incorporated crop residues.

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[2]Estimates for N-recovery are referred to as "N-recovery based on fertilizer N applied", rather than "fertilizer N-recovery", due to the presence of a N-fixing crop in certain treatments.

[3]The N-balance sheet was only prepared for 1989, as N-uptake by intercrops was determined only for that year.

In the grain system, harvested corn consisted of grain dry matter, and soil-incorporated crop residues comprised corn stover, seeded intercrops and weeds. In the silage system, harvested corn was the total above-ground dry matter, and soil-incorporated crop residues consisted of the seeded intercrops and weeds.

CHAPTER THREE

RESULTS

3.1 Intercrop Biomass and N-uptake

Results are presented for the effect of corn systems, intercrop species, and N fertilizer on above-ground biomass and N-uptake of three intercrop yield components: seeded intercrops, weeds and the total intercrop growth (seeded intercrops plus weeds). For a given component (seeded intercrops, weeds or total intercrop growth), main effects of a single factor are not discussed in the presence of interactions.

3.1.1 Intercrop Biomass

Seeded Intercrop Biomass

Intercrop species had an effect on seeded intercrop biomass in 1988 at the Ste. Rosalie site (Table 3.1). Intercrop growth was poor for both species in that site-year. Seeded red clover had a greater biomass (0.28 t/ha) when compared with seeded ryegrass (0.16 t/ha) intercrops.

An interaction between corn systems and intercrop species occurred at the Ste. Rosalie site in 1989, where seeded ryegrass had a lower biomass than seeded red clover intercrops only in the grain system (Tables 3.1 and 3.2).

There was no effect of N fertilizer on the biomass of seeded intercrops.

Weed Biomass

The effects of corn systems and intercrop species on weed biomass were modified by two-way interactions between these factors (Table 3.1). The interactions occurred at the Chicot site in 1988 and at the Ste. Rosalie site in 1989 (Table 3.1), and in both cases, a greater amount of weeds was found in ryegrass-grain treatments compared with weeds in either red clover-grain or ryegrass-silage treatments (Table 3.2). The sites differed, however, in that at the Chicot site, a greater amount of weeds was also found in ryegrass-silage compared with red clover-silage treatments, whereas corresponding treatments at the Ste. Rosalie site did not differ with respect to amount of weeds (Table 3.2).

There was no effect of N fertilizer on weed biomass (Table 3.1).

Total Intercrop Biomass

Both corn systems and intercrop species had an effect on total intercrop biomass, and some two-way interactions were also present for this variable.

The corn system effect occurred in 1989 at the Ste. Rosalie site (Table 3.1), where a greater total biomass was found in the grain (1.57 t/ha) compared with silage (1.20 t/ha) system. In the previous year at the same site, a greater total intercrop biomass was obtained with red clover (0.45 t/ha) compared with ryegrass (0.28 t/ha) treatments.

In an interaction between corn systems and intercrop species at the Chicot site in 1988, ryegrass treatments had a greater total biomass than red clover treatments in both corn systems, but differences between species were greater in the grain system (Table 3.2).

N fertilizer had no influence on total intercrop biomass (Table 3.1).

Table 3.1 Significance of F-values from analysis of variance of intercrop (seeded intercrop), weed, and total (seeded intercrop plus weed) biomass and N-uptake at the Chicot and Ste. Rosalie sites.

		Chicot			Ste. Rosalie		
Source	df	Intercrop	Weed	Total	Intercrop	Weed	Total
		Probability of > F					
				Biomass 1988			
S	1	ns	ns	ns	ns	ns	ns
Err . (a)	3						
I	1	ns	**	**	*	ns	*
N	2	ns	ns	ns	ns	ns	ns
I x N	2	ns	ns	ns	ns	ns	ns
S x I	1	ns	*	*	ns	ns	ns
S x N	2	ns	ns	ns	ns	ns	ns
S x I x N	2	ns	ns	ns	ns	ns	ns
Error (b)	30						
				1989			
S	1	ns	ns	ns	ns	*	*
Error (a)	3						
I	1	ns	ns	ns	*	ns	ns
N	2	ns	ns	ns	ns	ns	ns
I x N	2	ns	ns	ns	ns	ns	ns
S x I	1	ns	ns	ns	*	*	ns
S x N	2	ns	ns	ns	ns	ns	ns
S x I x N	2	ns	ns	ns	ns	ns	ns
Error (b)	30						
				N-uptake 1989			
S	1	ns	ns	ns	ns	ns	ns
Error (a)	3						
I	1	ns	ns	ns	*	ns	ns
N	2	ns	ns	ns	ns	*	*
lin	1	ns	ns	ns	ns	ns	ns
quad	1	ns	ns	ns	ns	*	*
I x N	2	ns	ns	ns	ns	ns	ns
S x I	1	ns	ns	ns	ns	ns	ns
S x N	2	ns	ns	ns	ns	ns	ns
S x I x N	2	ns	ns	ns	ns	ns	ns
Error (b)	30						

*, ** significant at the .05 and .01 level, respectively
ns = not significant
S = corn systems N = N fertilization I = intercrop species
lin, quad = linear, quadratic ($p<.05$), respectively

Table 3.2 Effect of the interaction between corn systems and intercrop species on IC (seeded intercrop), weed, and total (seeded intercrop plus weed) biomass at the Chicot and Ste. Rosalie sites.

Corn system	Intercrop species	1988 IC	1988 Weed	1988 Total	1989 IC	1989 Weed	1989 Total
		Biomass (t/ha)					
				Chicot			
Grain	Ryegrass (RG)	1.13	2.78	3.91	0.88	0.61	1.49
	Red clover (RC)	0.88	0.14	1.02	1.04	0.45	1.49
Silage	Ryegrass (RG)	1.03	2.00	3.03	1.07	0.53	1.60
	Red clover (RC)	1.22	0.18	1.40	0.95	0.66	1.61
Contrast							
Grain:	RG vs RC	nd	**	**	nd	nd	nd
Silage:	RG vs RC	nd	**	**	nd	nd	nd
RG.	Grain vs silage	nd	*	*	nd	nd	nd
RC:	Grain vs silage	nd	ns	ns	nd	nd	nd
				Ste. Rosalie			
Grain	Ryegrass (RG)	0.20	0.10	0.30	0.83	0.71	1.54
	Red clover (RC)	0.23	0.14	0.37	1.12	0.48	1.60
Silage	Ryegrass (RG)	0.13	0.13	0.26	0.75	0.42	1.17
	Red clover (RC)	0.34	0.21	0.56	0.93	0.34	1.27
Contrast							
Grain:	RG vs RC	nd	nd	nd	*	*	nd
Silage:	RG vs RC	nd	nd	nd	ns	ns	nd
RG:	Grain vs silage	nd	nd	nd	ns	*	nd
RC:	Grain vs silage	nd	nd	nd	ns	ns	nd

Contrast = single degree of freedom contrast
nd = not determined (simple effects were not determined when the interaction effect was not significant)
*, ** significant at the .05 and .01 level, respectively
ns = not significant

3.1.2 Intercrop N-uptake

Seeded Intercrop N-uptake

There was no effect of corn systems or N fertilization on seeded intercrop N-uptake (Table 3.1). Intercrop species had a small effect at the Ste. Rosalie site in 1989 (Table 3.1), where N-uptake was higher for seeded red clover compared with ryegrass intercrops. However, both the amounts of N taken up and differences between species (20 and 14 kg N/ha, for red clover and ryegrass, respectively) were small.

Total Intercrop and Weed N-uptake

A small effect of N fertilizer on total N-uptake was found at the Ste. Rosalie site in 1989, as a result of an increase in the uptake of N by weeds (Table 3.1). The amount of N involved was of little agronomic importance, however. At this site, weed N-uptake increased quadratically from 7 at the 0 N rate to 16 kg N/ha at the 140 kg N/ha rate.

3.2 Corn Dry Matter Yield and N-uptake

The dry matter (DM) yield and N-uptake of corn are presented for both above-ground total DM and grain and stover DM. Results are presented on a total DM basis for all comparisons that include the effects of corn systems. Grain and stover DM yield and N-uptake (grain system only) were analyzed without corn systems included as a factor; consequently, results for these corn yield components are presented separately.

As noted before, for a given variable within a given site-year, main effects of a single factor are not discussed in the presence of interactions.

3.2.1 Total Dry Matter Yield and N-uptake

Total Dry Matter Yield

Corn systems had an effect on corn total DM yields at both sites in 1989 (Table 3.3), and in both cases, corn yields were higher in the silage compared to grain system (Table 3.4[4]). Corn yields were low in both systems and at both sites in this year, and particularly low in the grain system at the Ste. Rosalie site. Two interactions with corn systems had an effect on total DM yield in 1988: one, with intercrop species at the Chicot site, and the other, with N fertilization at the Ste. Rosalie site (Table 3.3).

In 1988 at the Chicot site, corn total DM yields were greater with red clover compared with ryegrass in both corn systems, and differences were particularly great in the grain system (Table 3.5). Higher corn yields with red clover intercrops in the grain compared with silage system, were largely the result of the high dry matter accumulation in corn grain associated with legume intercrops (Tables 3.6 and 3.7). A N-rate-corn system interaction at the Ste. Rosalie site in this year, resulted in a linear total DM yield response to N in the silage system and a quadratic response in the grain system; differences between yields with respect to both systems and N-rates, however, were not great (Table 3.4).

In 1989, corn total DM yields in both corn systems were higher with red clover compared to ryegrass intercrops at the Chicot site, and higher with ryegrass compared to red clover intercrops at the Ste. Rosalie site (data not shown). At both sites, corn yields and yield differences were smaller in 1989 compared with 1988.

Effects of N-fertilizer on corn total DM yield were more consistently related to site than to either corn systems or intercrop species. At the Chicot site, corn total DM yields increased quadratically with increasing amounts of N, whereas at the Ste. Rosalie site, the increase in corn yield was mostly linear (Table 3.4).

[4]Not all main effects of corn system presented in Table 3.4 are discussed, because of the presence of interactions.

Table 3.3 Significance of F-values from analysis of variance of corn above-ground total dry matter (DM) yield and N-uptake at the Chicot and Ste. Rosalie sites.

Source	df	Chicot 1988	Chicot 1989	Ste. Rosalie 1988	Ste. Rosalie 1989
		------------- Probability of > F -------------			
			Total DM yield		
S	1	**	*	ns	**
Error (a)	3				
I	1	**	*	*	**
N	2	**	**	**	**
lin	1	**	**	**	**
quad	1	*	**	*	ns
I x N	2	ns	ns	ns	ns
S x I	1	*	ns	ns	ns
S x N	2	ns	ns	*	ns
S x I x N	2	ns	ns	ns	ns
Error (b)	30				
			Total DM N-uptake		
S	1	**	**	ns	**
Error (a)	3				
I	1	**	**	ns	*
N	2	**	**	**	**
lin	1	**	**	**	**
quad	1	ns	*	ns	ns
I x N	2	ns	ns	ns	ns
S x I	1	**	ns	ns	ns
S x N	2	ns	*	ns	ns
S x I x N	2	ns	ns	ns	ns
Error (b)	30				

*, ** significant at the .05 and .01 level, respectively
ns = not significant
S = corn systems N = N fertilization I = intercrop species
lin, quad = linear, quadratic ($p<.05$), respectively

Table 3.4 Main and interaction effects of corn systems and level of N-fertilization on corn total dry matter (DM) yield and N-uptake at the Chicot and Ste.Rosalie sites.

Level of N (kg N/ha)	1988 Grain		1988 Silage	1989 Grain		1989 Silage
	Corn system					
	Total DM yield					
	t/ha					
	Chicot					
0	8.6		7.5	5.0		6.4
70	12.0		10.7	8.0		10.1
140	13.0		10.0	9.5		10.1
Trend	quad		quad	quad		quad
Grain vs silage		**			*	
	Ste. Rosalie					
0	7.5		8.3	1.5		3.4
70	9.7		9.1	2.5		4.5
140	10.1		9.5	3.1		5.5
Trend	quad		lin	lin		lin
Grain vs silage		ns			**	
	Total DM N-uptake					
	kg N/ha					
	Chicot					
0	97		73	44		64
70	148		116	76		134
140	175		131	102		149
Trend	lin		lin	lin		quad
Grain vs silage		**			**	
	Ste. Rosalie					
0	78		90	13		36
70	116		106	22		55
140	130		119	32		74
Trend	lin		lin	lin		lin
Grain vs silage		ns			**	

*, ** significant at the .05 and .01 level, respectively ns = not significant Trend = orthogonal polynomial trend comparison; within a given site year, a dissimilar trend (lin, quad) for corn systems indicates a corn system-N rate interaction
lin, quad = linear, quadratic ($p<.05$), respectively

Table 3.5 Effect of the interaction between corn systems and intercrop species on corn total dry matter (DM) yield and N-uptake at the Chicot site in 1988.

Corn system	Intercrop species	Total DM yield	Total DM N-uptake
		---- t/ha ----	---- kg N/ha ----
Grain	Ryegrass (RG)	8.2	104
	Red clover (RC)	14.1	177
Silage	Ryegrass (RG)	7.6	93
	Red clover(RC)	11.2	121
Contrast			
Grain:	RG vs RC	**	**
Silage:	RG vs RC	*	**
RG:	Grain vs silage	ns	ns
RC:	Grain vs silage	*	**

Contrast = single degree of freedom contrast
*, ** significant at the .05 and .01 level, respectively
ns = not significant

Total Dry Matter N-uptake

Corn systems had an effect on total dry matter (DM) uptake of N by corn at both sites in 1989, and at the Chicot site in 1988 (Table 3.3). In 1989 at the Ste. Rosalie site, more N was taken up by corn total DM in the silage compared with grain system (Table 3.4). At the Chicot site, corn system effects on this variable were modified by interactions: between corn systems and intercrop species in 1988, and between corn systems and N fertilization in 1989 (Table 3.3).

At the Chicot site in 1988, total DM N-uptake by corn was greater with red clover compared with ryegrass in both corn systems, but the amount of N-uptake and magnitude of differences between intercrop treatments was greater in the grain system (Table 3.5). As was noted for total DM yield, higher N-uptake with red clover intercrops in the grain system was the result of a high uptake of N by grain, as there was no difference between intercrop treatments with respect to uptake of N by stover (Table 3.7). In 1989, an interaction between N-rate and corn systems resulted in linear total DM N-uptake in the grain system and quadratic uptake in the silage system (Table 3.4).

At the Ste. Rosalie site, intercrop species had little effect on total DM N-uptake by corn in either year of the experiment. In 1989, corn total DM N-uptake was greater under ryegrass compared with red clover intercrops (data not shown); in this site-year, however, differences were of little agronomic significance. Total DM uptake of N by corn was higher with red clover intercrops in both corn systems at the Chicot site in 1989 (data not shown). The amount of uptake and differences between intercrop treatments was less in this year than in 1988, however.

N fertilizer consistently increased corn total DM N-uptake, and in most cases, the increase in N-uptake with increasing amounts of N was linear (Table 3.4).

3.2.2. Grain and Stover Dry Matter Yield and N-uptake

Dry Matter Yield

Intercrop species had an effect on grain or stover dry matter (DM) yield in most site-years (Table 3.6). In most cases, however, DM yield differences between intercrop treatments were small. In 1988 at the Chicot site, both grain and stover DM yields were greater with red clover compared with ryegrass intercrops (Table 3.7). Stover DM yields were also greater with red clover intercrops at the Ste. Rosalie site in this year. Grain DM yields were higher with ryegrass compared with red clover intercrops at the Ste. Rosalie site in 1989; in this site year, however, yield differences were not agronomically important (Table 3.7).

N fertilizer had an effect on grain DM yields in all site-years, and both linear and quadratic yield responses were obtained (Tables 3.6 and 3.8). The stover DM yield response to applied N was linear at both sites in 1988, and either quadratic or not significant in 1989 (Tables 3.6 and 3.8).

There was no interaction between intercrop species and N-fertilization for either DM yield or N-uptake in any site-year.

N-uptake

In 1988 at the Chicot site, greater amounts of N were taken up by grain DM with red clover compared with ryegrass intercrops. There was no difference between intercrop treatments for uptake of N by stover in this site-year (Table 3.7). In the following year at this site, stover N-uptake was greater with red clover compared with ryegrass intercrops; differences in N-uptake were not great, however.

N fertilizer consistently increased the uptake of N by grain and stover DM (Table 3.8). The N-uptake response to applied N was linear for stover in all cases, and both linear and quadratic for grain (Table 3.8).

Table 3.6 Significance of F-values from analysis of variance of grain and stover dry matter (DM) yield and N-uptake in the grain corn system at the Chicot and Ste. Rosalie sites.

		Chicot				Ste. Rosalie			
		1988		1989		1988		1989	
Source	df	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
		Probability of > F							
		DM yield							
I	1	**	**	ns	ns	ns	**	*	ns
N	2	**	*	**	**	**	**	**	ns
lin	1	**	*	**	**	**	**	**	ns
quad	1	ns	ns	*	*	**	ns	ns	ns
I x N	2	ns	ns	ns	ns	ns	ns	ns	ns
		N-uptake							
I	1	**	ns	ns	*	ns	ns	*	ns
N	2	**	**	**	**	**	**	**	**
lin	1	**	**	**	**	**	**	**	**
quad	1	ns	ns	*	ns	*	ns	ns	ns
I x N	2	ns	ns	ns	ns	ns	ns	ns	ns

*, ** significant at the .05 and .01 level, respectively
ns = not significant
I = intercrop species N = N fertilization
lin, quad = linear, quadratic (p<.05), respectively

Table 3.7 Effect of intercrop species on grain and stover dry matter yield and N-uptake in the grain corn system at the Chicot and Ste. Rosalie sites.

Intercrop species	Chicot 1988 Grain	Chicot 1988 Stover	Chicot 1989 Grain	Chicot 1989 Stover	Ste. Rosalie 1988 Grain	Ste. Rosalie 1988 Stover	Ste. Rosalie 1989 Grain	Ste. Rosalie 1989 Stover
	DM yield t/ha							
R.grass (RG)	3.5	4.7	3.5	3.6	4.3	4.6	1.4	1.3
R.clover (RC)	8.2	5.9	3.5	4.4	4.3	5.0	1.0	1.1
RG vs RC	**	**	ns	ns	ns	**	*	ns
	N-uptake kg N/ha							
R.grass (RG)	58	44	35	34	69	37	14	11
R.clover (RC)	130	47	35	44	68	42	10	10
RG vs RC	**	ns	ns	*	ns	ns	*	ns

*, ** significant at the 0.05 and 0.01 level, respectively
ns = not significant
R.grass = ryegrass   R.clover = red clover

Table 3.8 Effect of level of N-fertilization on grain and stover dry matter (DM) yield and N-uptake in the grain corn system at the Chicot and Ste.Rosalie sites.

Level of N (kg N/ha)	Chicot 1988 Grain	Chicot 1988 Stover	Chicot 1989 Grain	Chicot 1989 Stover	Ste. Rosalie 1988 Grain	Ste. Rosalie 1988 Stover	Ste. Rosalie 1989 Grain	Ste. Rosalie 1989 Stover
	DM yield t/ha							
0	4.0	4.6	1.8	3.2	3.1	4.4	0.6	1.0
70	6.1	5.5	4.1	3.9	4.9	4.8	1.3	1.2
140	7.5	5.7	4.5	5.0	4.8	5.2	1.7	1.5
Trend	lin	lin	quad	quad	quad	lin	lin	ns
	N-uptake kg N/ha							
0	64	35	18	25	47	31	6	7
70	98	50	41	35	76	40	13	9
140	122	54	45	56	82	48	17	15
Trend	lin	lin	quad	lin	quad	lin	lin	lin

Trend = orthogonal polynomial trend comparison
lin, quad = linear, quadratic (p<.05), respectively

3.3 Crop Residues

Soil incorporated crop residues consisted of total intercrop biomass (seeded intercrops plus weeds), and crop residues from corn. Crop residues from corn (i.e., corn stover) were only available for soil-incorporation in the grain system.

Corn systems had an effect on crop residue production in both years at the the Chicot site, and in 1989 at the Ste. Rosalie site (Table 3.9). In all cases, the grain system produced a greater amount of crop residues than the silage system (Tables 3.10 and 3.11). At both sites in 1989, the corn system effect was modified by an interaction with N-rate: in the grain system, crop residue production increased linearly with increasing amounts of N fertilizer, whereas in the silage system, there was no effect of added N on the amount of crop residues produced (Table 3.11).

In 1988 at the Chicot site, crop residue production was greater with ryegrass compared with red clover intercrops in both corn systems (Table 3.10). There was no effect of intercrop species on the amount of crop residues produced in either year at the Ste. Rosalie site.

Table 3.9 Significance of F-values from analysis of variance of the amount of crop residues produced at the Chicot and Ste. Rosalie sites.

		Chicot		Ste. Rosalie	
Source	df	1988	1989	1988	1989
		Probability of > F			
S	1	**	**	ns	**
Error (a)	3				
I	1	**	ns	ns	ns
N	2	ns	ns	ns	*
lin	1	ns	ns	ns	**
quad	1	ns	ns	ns	ns
I x N	2	ns	ns	ns	ns
S x I	1	ns	ns	ns	ns
S x N	2	ns	**	ns	**
S x I x N	2	ns	ns	ns	ns
Error (b)	30				

*, ** significant at the .05 and .01 level, respectively
ns = not significant
S = corn systems N = N fertilization I = intercrop species
lin, quad = linear, quadratic (p<.05), respectively

Table 3.10 Main effects of corn systems and intercrop species on the amount of crop residues produced at the Chicot site in 1988.

Intercrop species	Corn System: Grain (Gr)	Corn System: Silage (Si)	Species mean
	Crop residues t/ha		
Ryegrass (RG)	6.9	1.4	4.2
Red clover (RC)	8.6	3.0	5.8
Systems mean	7.8	2.2	
RG vs RC	**		
Gr vs Si	**		

** significant at the .01 level
ns = not significant

Table 3.11 Effect of the interaction between corn systems and level of N-fertilization on the amount of crop residues produced at the Chicot and Ste.Rosalie sites in 1989.

Level of N (kg N/ha)	Chicot: Grain	Chicot: Silage	Ste. Rosalie: Grain	Ste. Rosalie: Silage
	Crop residues t/ha			
0	4.8	1.9	2.3	1.3
70	5.4	1.4	2.7	1.2
140	6.4	1.5	3.3	1.2
Trend	lin	ns	lin	ns

Trend = orthogonal polynomial trend comparison lin = linear
ns = not significant

3.4 Soil C and N

3.4.1 Soil Organic C and Total N

There was no effect of corn systems, intercrop species or N fertilizer rate on either soil organic C or total N after two years. An exception was found at the Ste. Rosalie site, where an interaction among the three factors had an effect on soil organic C (Tables 3.12 and 3.13).

Table 3.12 Significance of F-values from analysis of variance of soil total N and organic C in the 0- to 20-cm depth at the Chicot and Ste. Rosalie site in 1989.

Source	df	Total N (%)	Organic C (%)	Total N (%)	Organic C (%)
		Chicot		Ste.Rosalie	
S	1	ns	ns	ns	ns
Error (a)	3				
I	1	ns	ns	ns	ns
N	1	ns	ns	ns	ns
S x N	1	ns	ns	ns	ns
S x I	1	ns	ns	ns	ns
S x N	1	ns	ns	ns	ns
S x I x N	1	ns	ns	ns	**
Error (b)	30				

** significant at the .01 level
ns = not significant
S = corn systems   I = intercrop species   N = N fertilization

Table 3.13 Effect of corn systems, intercrop species and level of N-fertilization on soil organic C in the 0- 20-cm depth at the Ste. Rosalie site in 1989.

Corn system	Grain		Silage	
Intercrop species	Ryegrass	Red clover	Ryegrass	Red clover
	Soil organic C (%) (0-20 cm depth)			
Level of N (kg N/ha)				
0	3.10	3.16	2.95	3.03
70	2.45	3.64	3.63	2.86
140	3.51	2.60	3.19	3.28
Trend	ns	ns	quad	lin

Trend = orthogonal polynomial trend comparison
ns = not significant
lin, quad = linear, quadratic ($p<.05$), respectively

3.4.2 Soil Inorganic N

Corn systems, intercrop species and N fertilization all had an effect on soil inorganic N. Significant two-way and three-way interactions between factors were also present at some depths (Table 3.14). Main effects of a single factor at a given sampling depth cannot be discussed in the presence of interactions; consequently, interaction effects are presented before main effects.

3.4.2.1 Three-way Interaction Effects on Soil Inorganic N

An interaction effect of all three factors on soil N was found in the fall of 1988 at both sites in the 0-60 cm depth. The effect was also present in the 40-60 cm depth at the Ste. Rosalie site (Table 3.14). A similar interaction was found at both sites, in that the increase in soil N was quadratic under ryegrass in grain and under red clover in silage, but linear under red clover in grain and under ryegrass in silage (Table 3.15).

3.4.2.2 Two-way Interaction Effects on Soil Inorganic N

A few two-way interactions between corn systems and intercrop species were noted; in the Chicot soil in fall 1988 at the 0-20 cm depth and in spring 1989 at the 20-40 cm depth, and in the Ste. Rosalie soil in fall 1989 at the 40-60 cm depth (Table 3.14). At the Chicot site, ryegrass treatments had higher soil N levels than red clover in the grain system, whereas there was no difference between intercrop treatments in the silage system (Table 3.16). At the Ste. Rosalie site, higher soil N under red clover intercrops was found in the silage compared to grain system; differences in soil N values, however, were small (Table 3.16).

Table 3.14 Significance of F-values from analysis of variance of soil inorganic N in the 0- to 60-cm depth at the Chicot and Ste. Rosalie sites.

		Soil inorganic N							
		Sampling depth (cm)							
Source	df	0-20	20-40	40-60	0-60	0-20	20-40	40-60	0-60
		Fall 1988							
		Chicot				Ste. Rosalie			
S	1	ns	ns	ns	ns	ns	ns	ns	ns
Error (a)	3								
I	1	**	ns	ns	**	ns	ns	ns	ns
N	2	**	**	*	**	**	**	**	**
lin	1	**	**	**	**	**	**	**	**
quad	1	*	**	ns	**	ns	*	*	*
I x N	2	*	ns	ns	ns	ns	ns	ns	ns
S x I	1	**	ns	ns	ns	ns	ns	ns	ns
S x N	2	ns	ns	ns	ns	ns	ns	ns	ns
S x I x N	2	ns	ns	ns	*	ns	ns	**	**
Error (b)	30								
		Spring 1989							
		Chicot				Ste. Rosalie			
S	1	ns	*	ns	*	ns	ns	ns	ns
Error (a)	3								
I	1	ns	ns	ns	ns	ns	ns	*	ns
N	2	ns	*	**	**	**	**	**	**
lin	1	ns	*	**	**	**	**	**	**
quad	1	ns	ns	ns	ns	ns	ns	ns	ns
I x N	2	ns	ns	ns	ns	ns	ns	ns	ns
S x I	1	ns	**	ns	ns	ns	ns	ns	ns
S x N	2	ns	ns	ns	ns	ns	ns	ns	ns
S x I x N	2	ns	ns	ns	ns	ns	ns	ns	ns
Error (b)	30								
		Fall 1989							
		Chicot				Ste. Rosalie			
S	1	ns	*	ns	ns	ns	ns	ns	ns
Error (a)	3								
I	1	**	*	ns	**	ns	ns	ns	ns
N	2	ns	ns	**	*	**	**	**	**
lin	1	*	ns	ns	**	*	**	**	**
quad	1	*	ns	ns	ns	ns	ns	ns	ns
I x N	2	ns	ns	ns	ns	ns	ns	ns	ns
S x I	1	ns	ns	ns	ns	ns	ns	*	ns
S x N	2	ns	ns	ns	ns	ns	ns	ns	ns
S x I x N	2	ns	ns	ns	ns	ns	ns	ns	ns
Error (b)	30								

*, ** significant at the .05 and .01 level, respectively
ns = not significant S = corn systems I = intercrop species
N = N fertilization lin, quad = linear, quadratic ($p<.05$)

Table 3.15 Effect of the interaction between corn systems, intercrop species and level of N-fertilization on soil inorganic N in the 0- to 60-cm depth at the Chicot and Ste. Rosalie sites in the fall of 1988.

Corn system / Intercrop species	Soil inorganic N			
	Grain		Silage	
	Ryegrass	Red clover	Ryegrass	Red clover
Level of N (kg N/ha)	kg-(NH_4+NO_3)-N/ha			
	Chicot			
0	34.1	19.1	22.3	20.5
70	35.6	27.3	31.2	26.9
140	82.4	42.0	48.9	61.7
Trend	quad	lin	lin	quad
	Ste. Rosalie			
0	15.0	21.3	15.6	21.1
70	20.0	37.6	43.9	36.8
140	104.0	67.0	58.4	96.7
Trend	quad	lin	lin	quad

Trend = orthogonal polynomial trend comparison
lin, quad = linear, quadratic ($p<.05$), respectively

Only one interaction of intercrop species with N rate was found; in the fall of 1988 at the Chicot site, in the 0-20 cm depth (Table 3.14). As fertilizer N was increased from 0 to 140 kg N/ha, soil N increased linearly under red clover intercrops (from 6.6 to 12.6 kg N/ha) but quadratically under ryegrass (from 11.8 to 26.6 kg N/ha). As noted earlier, soil N levels were higher under ryegrass intercrops.

Table 3.16 Effect of the interaction between corn systems and intercrop species on soil inorganic N at various sampling depths at the Chicot and Ste. Rosalie sites.

Corn system	Intercrop species	Soil inorganic N, Sampling depth (cm) 0-20	20-40	40-60	0-60
		kg (NH4+NO3)-N/ha			
		Chicot, fall 1988			
Grain	Ryegrass (RG)	23.4	15.8	10.1	49.3
	Red clover (RC)	10.3	11.6	9.5	31.4
Silage	Ryegrass (RG)	11.6	10.9	11.6	34.1
	Red clover (RC)	8.6	18.1	10.5	37.2
Contrast					
Grain:	RG vs RC	**	nd	nd	**
Silage:	RG vs RC	ns	nd	nd	ns
RG:	Grain vs silage	**	nd	nd	**
RC:	Grain vs silage	ns	nd	nd	ns
		Spring 1989			
Grain	Ryegrass (RG)	26.3	20.9	15.1	62.3
	Red clover (RC)	17.6	13.7	15.7	47.0
Silage	Ryegrass (RG)	32.3	12.9	11.0	56.2
	Red clover (RC)	29.3	15.9	14.5	59.7
Contrast					
Grain:	RG vs RC	nd	**	nd	*
Silage:	RG vs RC	nd	ns	nd	ns
RG:	Grain vs silage	nd	**	nd	ns
RC:	Grain vs silage	nd	ns	nd	ns
		Ste. Rosalie, fall 1989			
Grain	Ryegrass (RG)	10.8	6.2	5.3	22.3
	Red clover (RC)	13.1	4.7	3.8	21.6
Silage	Ryegrass (RG)	17.9	5.2	4.7	27.8
	Red clover (RC)	12.2	7.5	6.9	26.6
Contrast					
Grain:	RG vs RC	nd	nd	ns	ns
Silage:	RG vs RC	nd	nd	*	ns
RG:	Grain vs silage	nd	nd	ns	ns
RC:	Grain vs silage	nd	nd	**	*

Contrast = single degree of freedom contrast
nd = not determined (simple effects were not determined when the interaction effect was not significant)
*, ** significant at the .05 and .01 level, respectively
ns = not significant

3.4.2.3 Main Effects on Soil Inorganic N

Corn systems had a small effect on soil inorganic N in the fall of 1989 at the Chicot site (Table 3.14). Soil N was higher under the silage system compared to grain at 20-40 cm; the difference in values, however, (8.0 kg and 6.1 kg N/ha for silage and grain, respectively) was of little agronomic significance.

Intercrop species effects were noted at several depths in the fall of 1989 in the Chicot soil, whereas species effects were noted at only one depth in the Ste. Rosalie soil in the spring of 1989 (Table 3.14). At the Chicot site, soil inorganic N was higher under ryegrass compared with red clover in both 0-20 and 20-40 cm depths (Tables 3.14 and 3.17). At the Ste. Rosalie site, a small difference was found in the spring of 1989 at the 40-60 cm depth, where higher soil inorganic N was found under red clover compared to ryegrass (Table 3.17).

N fertilization had an effect on soil inorganic N at both sites in all samplings (Table 3.14). The effect in 1988 was modified by the two-way and three-way interactions discussed previously. Soil N increased linearly with added N in the 0-60 cm profile in all 1989 samplings (Tables 3.14 and 3.18). At the Chicot site in the spring, there was no effect of N rate at the 0-20 cm depth. Soil inorganic N increased linearly with added N, however, in both the 20-40 cm and 40-60 cm depths (Table 3.18). In the fall sampling of the Chicot soil, the effect of N rate on soil inorganic N was due to effects in the 0-20 cm depth. In this sampling, however, soil N decreased at the high fertilizer rate (Table 3.18).

At the Ste. Rosalie site, soil N increased linearly with added N at all sampling depths in 1989 (Tables 3.14 and 3.18). In the spring, while surface effects were absent in the Chicot soil, the effect of added N remained significant at the 0-20 cm depth in the Ste. Rosalie soil (Table 3.18). The influence of added N in the fall in the Ste. Rosalie soil was due to effects in the 0-20 cm depth. Unlike at the Chicot site, however, surface soil N at the Ste. Rosalie site increased at the high N rate (Table 3.18).

Table 3.17 Effect of intercrop species on soil inorganic N at various sampling depths at the Chicot and Ste. Rosalie sites.

Intercrop species	Soil inorganic N, Sampling depth (cm) 0-20	20-40	40-60	0-60
	---------- kg (NH4+NO3)-N/ha ----------			
	Chicot, fall 1989			
Ryegrass (RG)	11.1	9.0	9.1	29.2
Red clover (RC)	5.4	5.2	5.6	16.2
RG vs RC	**	*	ns	**
	Ste. Rosalie, spring 1989			
Ryegrass (RG)	31.3	15.4	8.4	55.1
Red clover (RC)	26.1	13.8	11.5	51.4
RG vs RC	ns	ns	*	ns

*, ** significant at the .05 and .01 level, respectively
ns = not significant

Table 3.18 Effect of level of N-fertilization on soil inorganic N at various sampling depths at the Chicot and Ste. Rosalie sites in 1989.

Level of N (kg N/ha)	Inorganic soil N, Sampling depth (cm) 0-20	20-40	40-60	0-60
	---------- kg (NH4+NO3)-N/ha ----------			
	Chicot			
	Spring			
0	23.2	14.3	8.8	46.3
70	27.6	14.1	10.3	52 0
140	27.5	18.8	22.0	68.3
Trend	ns	lin	lin	lin
	Fall			
0	5.0	5.3	9.1	19 4
70	10.3	6.5	5.0	21.8
140	8.4	9.1	8.7	26.2
Trend	quad	ns	ns	lin
	Ste. Rosalie			
	Spring			
0	20.9	7.9	5.6	34.4
70	27.0	13.5	8.6	49.1
140	38.3	22.3	14.9	75 5
Trend	lin	lin	lin	lin
	Fall			
0	5.6	3.5	3.0	12.1
70	12.9	4.6	4.6	22.1
140	22.0	9.7	7.9	39.6
Trend	lin	lin	lin	lin

Trend = orthogonal polynomial trend comparison
lin, quad = linear, quadratic ($p<.05$), respectively
ns = not significant

3.5 N-Recovery Based on Fertilizer N Applied

3.5.1 N-Recovery in Corn, Intercrops and Soil and Unaccounted for N

Results are presented for the effect of corn systems, intercrop species and N-rate on the amount of N recovered in corn total dry matter (corn), seeded intercrops plus weeds (IC), and soil, as well as the amount of unaccounted for N in silage and grain corn-intercrop systems. The N-uptake and soil N data used to estimate the recoveries is given in the Appendix: Table A1. N-uptake by intercrops was only determined in 1989; consequently, N-recovery in intercrops was only determined for that year.

Due to a high amount of variability in the original data, and the fact that variances were in some cases proportional to the means, data was log-transformed prior to statistical analysis. The statistics presented in Tables 3.19 and 3.20 are for the transformed data, whereas the means in Table 3.20 are the original N-recovery values.

Once transformed, there was little effect of factors other than N-rate on N-recovery values (Table 3.19). There was an effect of N-rate on N-recovery in soil at both sites in 1988 (Table 3.19). In both cases, more N was recovered in soil at the high compared to low rate of N fertilization (Table 3.20). N-rate had an effect on the recovery of N in corn in both 1988 and 1989 at the Chicot site (Table 3.19). In both years at this site, a higher percentage of N was recovered in corn at the low compared with the high N-rate (Table 3.20).

Table 3.19 Significance of F-values from analysis of variance of log-transformed N-recovery based on fertilizer N applied at the Chicot and Ste. Rosalie sites.

		log (N recovery + 1)							
		Chicot				Ste. Rosalie			
Source	df	Corn	IC	Soil	Unacc	Corn	IC	Soil	Unacc
		Probability of > F							
		1988							
S	1	ns		ns	ns	ns		ns	ns
Error (a)	3								
I	1	ns		ns	ns	ns		ns	ns
N	1	**		**	ns	ns		**	ns
I x N	1	ns		ns	*	ns		ns	ns
S x I	1	ns		ns	ns	ns		ns	ns
S x N	1	ns		ns	ns	ns		ns	ns
S x I x N	1	ns		ns	ns	ns		ns	ns
Error (b)	60								
CV (%)		23.8		44.9	69.5	28.2		48.1	81.4
		1989							
S	1	ns	ns	ns	ns	ns	ns	ns	ns
Error (a)	3								
I	1	ns	ns	ns	ns	ns	ns	ns	ns
N	1	*	ns	ns	ns	ns	ns	ns	ns
I x N	1	ns	ns	ns	ns	ns	ns	ns	ns
S x I	1	ns	ns	ns	ns	ns	ns	ns	ns
S x N	1	ns	ns	ns	ns	ns	ns	ns	ns
S x I x N	1	ns	ns	ns	ns	ns	ns	ns	ns
Error (b)	60								
CV (%)		15.8	19.2	46.1	70.4	28.5	24.0	65.2	79.6

*, ** significant at the .05 and .01 level, respectively
ns = not significant
S = corn systems N = rate of N fertilization
I = intercrop species CV = coefficient of variation
Corn = corn total dry matter IC = seeded intercrops plus weeds
Unacc = unaccounted for N

Table 3.20 Effect of N-rate on N recovery in corn total dry matter (corn), seeded intercrops plus weeds (intercrops), soil, and unaccounted for N at the Chicot and Ste. Rosalie sites.

	N recovery (%)[w]			
Level of N (kg N/ha)	Corn	Intercrops[v]	Soil	Unaccounted for N
		Chicot		
		1988		
70	71.6		10.7	18.7
140	47.6		26.5	26.4
70 vs 140	**		**	ns
		1989		
70	84.1	-20.3	8.9	10.8
140	59.9	-7.7	6.2	38.1
70 vs 140	*	ns	ns	ns
		Ste. Rosalie		
		1988		
70	38.7		13.5	32.3
140	29.1		22.3	22.3
70 vs 140	ns		**	ns
		1989		
70	23.2	2.3	14.7	62.9
140	25.1	3.6	19.7	55.3
70 vs 140	ns	ns	ns	ns

*, ** significant at the .05 and .01 level, respectively
ns = not significant
[w]Statistics for N-recovery were performed on log-transformed data, whereas the means presented are the original untransformed data.
[v]Negative recovery values resulted when N-uptake by intercrops was greater on unfertilized than on fertilized treatments (see Appendix: Table A1).

The interaction between N-rate and intercrop species had an effect on the amount of unaccounted for N at the Chicot site in 1988 (Table 3.19). The amount of unaccounted for N was similar at both low and high N-rates under ryegrass intercrops (38.3 vs 34.7%), whereas a greater amount of unaccounted for N was found at the high compared with low N-rate under red clover intercrops (18.0 vs 1.0 %).

In both years, the amount of N recovered in corn was lower and unaccounted for N was higher at the Ste. Rosalie compared with the Chicot site (Table 3.20).

3.5.2 N Balance Sheet for Corn-Intercrop Systems

Statistics for the data[a] from which the N balance sheet (Table 3.21) was constructed, have been presented in previous tables. In the following section, some of these tables are referred to in the presentation of the balance sheet, in order to account for differences in the amount of N removed from or retained by the system.

N Removed

A higher removal of N by harvested corn in the silage compared with grain system, was found at all rates of N fertilization (Table 3.21). In most cases, differences between systems were similar for low (70 kg N/ha) and high (140 kg N/ha) N rates. A greater removal of N by harvested dry matter in the silage system in 1989, was due to a higher N-uptake by corn total dry matter in this system compared with N-uptake of either grain dry matter or above-ground total dry matter in the grain system (Tables 3.4 and 3.8).

Intercrop species had little effect on the amount of N removed by harvested corn. An exception was at the Chicot site, where a greater removal of N by silage corn occurred with red clover compared with ryegrass intercrops (Tables 3.21 and 3.3).

[a]N-uptake by silage and grain corn, N-uptake by crop residues (corn stover, seeded intercrops plus weeds), and fall soil inorganic N.

Table 3.21 N-balance sheet: The amount of N removed from and retained by silage and grain corn-intercrop systems at the Chicot and Ste. Rosalie sites in 1989.

Intercrop species	Level of N (kg N/ha)	Corn System: Grain, N removed	Grain, N retained	Silage, N removed	Silage, N retained
		N-uptake (kg N/ha)			
		Chicot			
Ryegrass	0	19.7	72.4	51.5	65.5
	70	60.0	90.5	113.2	72.5
	140	70.2	120.3	138.7	67.4
Red clover	0	24.3	89.3	76.9	72.8
	70	60.6	86.2	154.9	51.3
	140	77.4	116.8	159.5	57.3
		Ste. Rosalie			
Ryegrass	0	15.3	35.4	35 2	41.9
	70	23.2	48.5	59.7	63.5
	140	43.4	96.2	78.1	57.9
Red clover	0	6.0	50.9	37.6	38.0
	70	22.1	49.8	49.2	51.4
	140	25.7	88.0	70.7	75.3

N removed = N taken up by harvested corn
N retained = fall soil inorganic N + N taken up by soil incorporated crop residues

N Retained

At the Chicot site, a greater amount of N was retained (recovered in soil and crop residues) by the grain compared with the silage system, and differences between systems were greatest at the high (140 kg N/ha) compared with the low (70 kg N/ha) N rate (Table 3.21). From crop residue and soil N data, differences between corn systems in terms of the amount of N retained were the result of N-uptake by corn stover residues in the grain system, as there was no difference between systems in terms of N-uptake by intercrops or fall soil N levels (Tables 3.1, 3.8 and 3.14). At the Ste. Rosalie site, differences between corn systems in terms of the amount of N retained were small, and only apparent at the high (140 kg N/ha) N-rate.

There was no consistent effect of intercrop species on the amount of N retained by the system at either site (Table 3.21).

CHAPTER FOUR

DISCUSSION

4.1 Intercrop Biomass as Affected by Corn Systems and Intercrop Species

The first hypothesis proposed that reduced corn-intercrop competition late in the season with silage production, would result in a greater intercrop biomass. This hypothesis was based on the assumption that the earlier harvest of corn in silage production compared with grain, would result in a late-season period of intercrop growth free from competition with corn. The hypothesis was rejected, as there was no effect of corn systems on the biomass of seeded intercrops at either site. When total biomass was considered (intercrops plus weeds), the grain corn system at the Ste. Rosalie site had a greater total intercrop biomass in 1989. This was primarily due to the greater biomass of weeds in that system compared with the silage system. Differences were not great, and thus it was not considered to indicate a trend.

One reason proposed for the failure to achieve higher intercrop yields under silage corn, is that silage harvesting operations damaged intercrop vegetation and subsequent growth was reduced. An additional reason however, is that competition from corn for N and water, appears to have prevented intercrops in either corn system from achieving high dry matter yields. Intercrop dry matter yields in this study (0.10-2.0 t/ha) were similar to those reported by other intercropping studies in this region (Tomar et al. 1988; Nanni and Baldwin 1987; Claude 1990), but lower than those reported by Scott et al. (1987) in the northeastern U.S. (1.0-3.0 t/ha). Furthermore, the short six week "competition-free" period after silage harvest was relatively cool and dry in both 1988 and 1989, resulting in a reduced intercrop growth potential during this less favorable period. The excellent fall growth of alfalfa following corn silage harvest in Nebraska reported by Nordquist and Wicks (1974), was for alfalfa under irrigated conditions, and with a longer growing season than occurs in Quebec. Under the experimental and climatic conditions of the present study, however, it is unlikely that intercrop growth would be greater in a silage compared to a grain corn system for the reasons given.

There were a few corn systems by intercrop species interactions for total intercrop biomass. At the Chicot site in 1988, ryegrass treatments had a higher total intercrop biomass compared with red clover in both corn systems, and differences between treatments were particularly great in the grain corn system. At this site however, the effect was due to the greater biomass of weeds in ryegrass-grain treatments, rather than to differences in the biomass of seeded intercrops. The severe weed infestation in ryegrass at the Chicot site was due to the fact that no herbicide was used on ryegrass plots in 1988 The other two-way interaction was at the Ste. Rosalie site in 1989, where red clover treatments had a higher intercrop biomass in the grain compared to silage system. Differences among treatments were not agronomically important, however.

In any case, it appears that intercrop biomass was not related consistently to any particular corn system or intercrop species. It also appears that for both corn systems and both intercrop species, weeds comprised a large proportion of the total intercrop biomass, emphasizing the importance of weed control in intercrop management.

4.2 Soil N and C as Affected by Corn Systems and Intercrop Species

The second hypothesis proposed that reduced corn-intercrop competition in silage production would result in higher soil N levels in either fall or spring, following plowdown of the intercrops. It was further speculated that greater intercrop growth in the silage system, could result in a greater contribution to the pool of soil organic C or N by intercrops in that system compared to the grain system. Finally, legume and non-legume intercrop species were compared as to their effect on soil N levels and N-recovery in the system.

4.2.1 Soil N and C as Affected by Corn Systems

There was essentially no corn system effect on soil inorganic N. A small effect in the fall of 1989 at the Chicot site, where soil N was higher under the silage system compared to grain at the 20-40 cm depth, was of little agronomic significance. The lack of a system effect on soil inorganic N is not surprising, as this second hypothesis was proposed as an anticipated consequence of the first, (ie., that the silage system would result in greater intercrop growth), which was rejected.

There was no consistent corn system effect on either soil total N or organic C after two years. An interaction among systems, species and N rate at the Ste. Rosalie site was difficult to interpret, and thought to be an artifact due to soil variability. As the first and second hypotheses proved incorrect, the lack of a system effect on soil C and N was to be expected. The amount of crop residue required to maintain soil C and N levels in rotations with corn has been estimated to be 6-7 t/ha/year (Larson et al. 1972; Cope et al. 1958; Liang 1989). The lack of added stover residues in the silage system compared to grain (and consequently greater loss of soil C and N (Barnhart et al. 1978)), means that a much higher intercrop biomass production would be necessary to maintain soil C and N in that system compared to grain. In this experiment, total intercrop biomass in the silage system was well below the critical values of 6-7 t/ha/year. Critical values for residue production were only obtained in the grain corn-intercrop system in one site-year of the experiment.

The N balance sheet for 1989, indicated that a greater removal of N by harvested corn occurred in the silage compared with the grain system at all rates of applied N. Furthermore, a lesser amount of N was retained (recovered in soil and crop residues) in this system compared with the grain system.

These results indicate that, not only was the contribution of N and C to soil from crop residues less in the silage system, but also that removal of added N from soil was greater in this system compared to the grain corn system.

Given the low residue return in the present study, it appears that soil C and N levels would decline in both corn systems over an extended period. Such an evaluation was not possible in this study, however, given the short duration of the experiment.

4.2.2 Soil N as Affected by Intercrop Species

There was no consistent effect of intercrop species on soil inorganic N at either site. The effect of two-way and three-way interactions, however, were noted at several samplirg depths. In both the fall of 1988 and spring of 1989 at the Chicot site, ryegrass treatments had higher soil N levels compared with red clover in the grain system, whereas there was no difference between intercrop species in the silage system. Ryegrass treatments also had a higher total intercrop biomass and lower total dry matter N-uptake by corn than red clover in both corn systems. Given that non-growing season soil temperatures were unlikely to favor significant N mineralization, high soil N levels in ryegrass-grain plots were more likely to have been the result of low N-uptake by corn, rather than a N contribution from incorporated ryegrass intercrops.

In the three-way interaction, the effect of corn systems, intercrop species and N-rate on soil inorganic N was less clear. At both sites in 1988, the increase in soil N was quadratic under ryegrass in grain and under red clover in silage, but linear under red clover in grain and under ryegrass in silage. Obviously a complex interaction is occurring, in this case however, the causes and effects of the interaction are too obscure to enable valid or meaningful prediction of soil N levels in a given system-intercrop species combination.

There was no advantage of red clover over ryegrass intercrops, in terms of a contribution to soil N, in any site year of the experiment. Second year N-benefits to corn from residual legume N could only be evaluated in one year of the experiment (section 4.3.2). The likelihood of such benefits occurring was not obvious, however, from the low amounts of residual N in red clover treatments in the fall of both years and spring of the second year of the experiment.

The ability of ryegrass to intercept and recycle NO_3-N has been noted by Groffman et al. (1987), who found lower losses of NO_3-N by leaching and denitrification in ryegrass treatments compared with red clover. In the present study, it was hoped that ryegrass intercrops might reduce fall soil N levels in treatments fertilized at the high N rate, thereby enhancing the overall recovery of fertilizer N in the system. The three-way interaction effect on soil N, indicated that intercrop species had an inconsistent effect on end of season soil accumulations of fertilizer N. End of season N-recovery estimates suggested no effect from intercrops species on N recovery in soil, and recovery of N in the intercrops themselves was low. The absence of a "sponge crop" (or N-intercepting) effect of ryegrass intercrops in the present study, was presumably the result of a low dry matter yield and N-uptake potential of the intercrops.

Values obtained for "unaccounted for N" were variable, and not related to a particular corn system. An interaction between intercrop species and N rate was found at the Chicot site in 1988, where a greater amount of unaccounted for N was obtained with red clover intercrops fertilized at the high compared with the low N rate. Greater amounts of unaccounted for N were also associated with the Ste. Rosalie site, where N rates appear to have exceeded crop assimilation capacity. Because crop residues from the previous season were still largely undecomposed in the spring when N was applied, it is likely that some of the fertilizer N was immobilized by soil microflora during the growing season. Short-term net immobilization of N would have increased estimates of unaccounted for N by temporarily removing N from both soil inorganic N and crop N-uptake reservoirs. The likelihood that N-immobilization was significant in the present study, was further supported by the fact that the highest values for unaccounted for N were obtained at the Ste. Rosalie site, where the greatest amount of organic C would have been available to soil microflora. Although no attempt was made to determine the possible pathways of N-loss, it is likely that most losses occurred through ammonia volatilization and/or denitrification. Leaching was unlikely to have been significant, as precipitation was low during the growing season, and residual soil inorganic N was low at the onset of the non-growing season.

Several studies have indicated the need for caution when interpreting estimates of unaccounted for N determined by the difference method, because of the large amount of systematic error associated with this method. Systematic errors are introduced when one or more of the pathways of N recovery or loss is omitted from the calculation procedure. Errors have been found to accumulate in the final department (i.e , unaccounted for N) when this is determined by difference (Legg and Meisenger 1982; Allison 1966). In the present study, a certain amount of the variability associated with estimates for unaccounted for N was probably the result of differences in the amount of N removed from the inorganic N pool by immobilization. Variability was undoubtedly also increased, however, by the imprecision associated with the estimation method used.

4.3 Corn Dry Matter Yield and N-Uptake as Affected by N Rate, Corn Systems, and Intercrop Species.

The third hypothesis proposed that in both silage and grain corn systems, there is a level of N fertilization that maximizes corn yields while optimizing intercrop growth. It was also speculated that higher corn yields and N-uptake by corn would result with a legume compared with non-legume species of intercrop.

4.3.1 Corn Dry Matter Yield and N-Uptake as Affected by N Rate and Corn Systems

Nitrogen fertilization consistently increased both total dry matter N-uptake and yield of corn. There was no main effect of corn systems on N-uptake; total dry matter yields, however, were higher in the silage compared to grain system at both sites in 1989. Some N-rate by corn system interactions were also present; linear and quadratic yield response trends were more consistently related to site, however, than to a particular corn system.

At the Chicot site, total dry matter yield response to applied N was quadratic, whereas the response was mostly linear at the Ste. Rosalie site. One interpretation of these trends is that, in terms of N-rates, near-maximum yields were more easily obtained at the Chicot than at the Ste. Rosalie site. Another interpretation, however, is suggested by comparisons with monocrop corn yields from previous experiments on these soils (Claude 1990; Tomar et al. 1986; Warnaars 1972). These comparisons indicate that corn total dry matter yields in the present study were 0-40% and 25-80% lower, at the Chicot and Ste. Rosalie sites, respectively, than those normally obtained on the same soils at these sites. In the presence of low yields, quadratic yield responses suggest that water stress or some other factor was limiting the potential of intercropped corn to exploit added N at the high rate. In the absence of monocrop controls, the degree to which low yields were due to low growing season precipitation, intercrop competition, or other factors, is not clear. It is likely, however, that a combination of factors was responsible for low corn yields, and that moisture stress increased the intensity of corn-intercrop competition for water.

Chicot Site

In 1988 at the Chicot site, despite a relatively low total dry matter yield and quadratic total dry matter yield response to N in the grain system, yields of grain increased linearly with added N , and at the high N rate were comparable (7.5 t/ha) to yields of monocrop grain corn obtained by Claude (1990) and Warnaars (1972) in previous experiments at the same site. This site-year differed from the others primarily in having a less severe moisture-deficit; a result of the more favorable distribution of growing-season precipitation in 1988 compared with 1989, and the greater capacity of soil to to supply plant-available water at the Chicot compared with the Ste. Rosalie site[6]. The high grain yields and linear yield response to added N obtained in the wetter site-year, further support the supposition that quadratic yield responses were the result of moisture stress rather than a fully exploited yield potential.

A mostly linear total dry matter N-uptake response to applied N at the Chicot site, suggested that N-uptake in both corn systems was limited by inadequate amounts of fertilizer N. Nitrogen recovery data, however, indicated that for all quadratic yield responses (total dry matter yield in the silage system in both years, and in the grain system in 1989), fertilizer N recovery in corn was higher at the low rate than at the high rate of applied N, whereas for the linear yield response (grain yield in 1988), a higher recovery of N occurred at the higher N rate. These results suggest that while increasing amounts of fertilizer N increased yields in both systems, N applied at the high rate was more effectively utilized by corn in the grain system compared with silage. That corn total dry matter yields were higher in the grain compared with the silage system in 1988 at the Chicot site, may be attributed to the

[6]Although the Ste. Rosalie soil was a clay and the Chicot soil a sandy loam, the finer-textured soil did not possess greater moisture-supplying ability, due to imperfect drainage and poor soil structure.

fact that silage corn was harvested prior to physiological maturity[7]. It is therefore likely that dry matter accumulation continued in the corn after silage harvest and was, in fact, not complete at the time of grain harvest. In 1989, although moisture contents of corn at harvest were similar to those obtained in the previous year, corn yields in the grain system were not higher than in the silage system. In this year, yield advantages that could have resulted from the additional period of growth in the grain system did not occur because of the limiting effects of moisture stress. In a year characterized by moisture deficit during pollination and early ear development, a greater yield reduction in the grain system compared with silage can be attributed to the critical role of water supply to ear-growth, and the typically greater contribution of ear-weight to total dry matter in grain corn (47-61 %) compared with silage corn (40-58 %) (Hanway 1963; Giskin and Efron 1986; Jokela and Randall 1989).

Ste. Rosalie Site

Both linear total dry matter N-uptake and corn yield responses to applied N, and even lower corn yields at the Ste. Rosalie compared with Chicot site, suggested that N was more limiting than water at this site. Although maximum N-uptake by corn was never obtained at this site, no evidence of an N deficiency was found in corn plant tissues[8]. Furthermore, low N-recoveries in corn at both N-rates, indicated that corn N-uptake was consistently less than the potential amount of uptake possible at the levels of N present. Both of these observations can be explained by the fact that the demand for N of corn is largely a function of its dry weight (Greenwood 1982). With such low

[7]The percentage of moisture in corn at harvest in both years at the Chicot site, was 43% and 72% in the grain and whole-plant silage, respectively. The percentage of moisture associated with physiological maturity of corn in Canada is 35% for grain and 65-70% for whole-plant silage (Agriculture Canada 1974).

[8]Total N content of grain and silage corn plant tissues at harvest (1.48 and 1.15 %, for corn grain and whole plant silage, respectively), were similar to N contents reported by Olson and Kurtz (1982) for corn grown under conditions where N was non-limiting.

amounts of corn dry matter present, low yields at the Ste. Rosalie site were probably the result of some factor other than insufficient levels of N. Evidence of soil desiccation (a hard, cracked soil surface) and low uptake of water by corn (wilting plants) at various times throughout both growing seasons, suggested low soil moisture and/or a low plant-availability of water to be the most likely other factor causing low yields.

Because of the slower movement of N and other nutrients to plant roots at low soil moisture contents, some studies have suggested that higher rates of fertilizer N than those applied in the present study are required for corn under limited soil moisture conditions (Warnaars 1972; Jokela and Randall 1989). At the Ste. Rosalie site, however, very low recoveries of N in corn at the low N rate were not improved by applying greater amounts of fertilizer N. Although corn yield reduction appeared to be caused primarily by moisture stress, other factors, such as poor soil aeration resulting from a compacted soil structure, may have been involved. With such low values for both N-uptake and N-recovery in corn, and a number of possible factors limiting corn yields, it was not possible to conclude that a higher N rate would have increased yields at the Ste Rosalie site.

4.3.2 Corn Dry Matter Yield and N-Uptake as Affected by Intercrop Species

Once the confounding effects of weeds was removed, there was little effect of intercrop species on either corn N-uptake or dry matter yield in either site-year. Intercrop species were found to have an inconsistent effect on corn yield in an adjacent experiment on these soils (Claude 1990).

In both years on the Ste. Rosalie soil, the effects of intercrop species on corn total dry matter N-uptake and yield were limited by moisture stress. Insufficient soil moisture resulted in poor intercrop growth in 1988, and low corn yields in 1989.

At the Chicot site, intercrop species effects on corn N-uptake and dry matter yield in 1988 were confounded with a greater weed infestation in ryegrass plots. In 1989, corn total dry matter N-uptake in both systems and yields in the silage system were higher with red clover intercrops. Corn yield differences were not great in this site-year, however. The evidence for N benefits from intercrop legumes from the adjacent study (Claude 1990) was inconclusive. In this experiment, silage corn appeared to be benefiting from a legume intercrop N-contribution, and supporting evidence was the fact that a greater amount of N was recovered in corn than was applied as fertilizer. As to whether this contribution was from residual N (N mineralized from the previous seasons legume biomass), or from a current season N-transfer or N-sparing effect (Simpson 1965; Haystead and Marriott 1979), was not determined. In any case, it must be emphasized that the evidence for an N-contribution was found only in one soil, one season and one corn system. Thus, conclusions about the N-contribution (let alone the corn yield benefit) from legume intercrops to corn remain tentative.

GENERAL CONCLUSIONS

After two years, earlier corn harvest in the silage system did not result in greater intercrop growth compared to later corn harvest in the grain system, due to both the effects of a sub-optimal growing period following silage harvest, and the damaging effects of the harvesting operation on subsequent intercrop growth. As no intercrop growth advantage was found in the silage system, no advantages in terms of soil N or yield of subsequent corn, were realized in this system compared to the grain system.

The lack of a contribution to soil total N and organic C in either system was attributed to low residue production. The lack of residues was particularly evident in the silage system. In southwestern Quebec, the potential for high dry matter production in corn-intercrop systems is limited by frequent soil moisture deficits and a short growing season. The use of intercrops is therefore not seen as a means of preventing soil C and N loss in silage corn systems in this region.

There was no significant soil N contribution by legume intercrops in either corn system, and intercrop species had an inconsistent effect on end of season accumulations of soil N in treatments fertilized at the high N rate. Thus, there appeared to be little difference between intercrop species in terms of either their contribution to soil N, or their ability to intercept and recycle residual NO_3-N. Moreover, intercrop species had essentially the same effect on soil N in each corn system. Soil N data obtained for one species/system combination, could therefore be extrapolated to the other.

In the silage system, a quadratic response to applied N in both years at the Chicot site indicated that in terms of N-rates, "near-maximum" corn total dry matter yields were obtained. Intercropped silage corn yields however, were still 30-40 % below the average obtained in previous experiments at this site, and it is likely that yields were limited by moisture deficits. Although maximum corn total dry matter yields were not obtained in the grain system, high grain yields were obtained in one favorable site-year. The higher total dry matter yields obtained in the grain compared with the silage system in this year, appeared to be due to the fact that silage corn was harvested prior to physiological maturity and dry matter accumulation continued in the corn after silage harvest. In all other cases, however, total dry matter yields were higher in the silage system, and yield advantages of the grain system that could have resulted from the additional period of growth did not occur because of the limiting effects of moisture stress. It is likely that in both systems, corn yields would have been increased by higher rates of applied N only in years that moisture was not limiting.

Intercrop species had little effect on corn yield. In one case, silage yields and N recovery in corn were higher with red clover intercrops, and there was evidence that corn was benefitting from a legume-N contribution. In this study however, N-transfer was an exceptional occurrence; in most cases, competition with corn for N and water by intercrops was severe, and similar for both legume and non-legume intercrop species Conclusions about the legume-N contribution to intercropped corn therefore remain, at best, tentative.

Suggestions for Future Work

1 Modify silage harvesting procedures, to minimize damage to intercrops and subsequent intercrop growth. One suggestion, is the use of a 4-row instead of a 2-row silage harvester, to reduce the number of intercrop rows over which tractor and harvester must pass (O'Halloran 1991).

2 Reduce intercrop competition with corn for N and water, to improve corn yields. Corn-intercrop competition could be reduced through a combination of increased rates of applied N, more effective weed control, and delayed intercrop seeding dates. Providing irrigation to intercrop-corn is not a practical option for most farmers at this time; the practice could have merit experimentally however, in allowing the dry matter production potential of the system in the absence of moisture stress, to be determined (O'Halloran 1991).

3 Include some monocrop corn plots at each experimental site. The data from these plots could be used, not so much for statistical comparisons as to provide "background" or control information, in standardizing yield and other data as well as confirming the presence of confounding factors

4. Include the use of a labelled N source applied to confined microplots, to improve the accuracy of quantitative N-recovery and N-balance determinations

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APPENDIX

Table A1. Data for N-recovery: Uptake of N by corn total dry matter (corn), seeded intercrops plus weeds (IC), and soil in silage and grain corn intercrop systems at the Chicot and Ste. Rosalie sites.

Intercrop species	Level of N (kg N/ha)	Corn system: Grain Corn	IC	Soil	Silage Corn	IC	Soil
		N-uptake (kg N/ha)					
				Chicot 1988			
Ryegrass	0	63.8		34.1	62.4		22.4
	70	99.9		35.9	99.4		31.2
	140	139.2		83.1	116.4		48.9
Red clover	0	122.2		14.2	83.9		20.5
	70	197.0		27.3	133.0		27.0
	140	211.4		45.0	145.7		61.7
				Chicot 1989			
Ryegrass	0	42.3	29.8	20.0	51.5	37.8	27.7
	70	91.9	34.8	23.8	113.2	29.9	42.7
	140	116.5	38.2	35.8	138.7	41.2	26.2
Red clover	0	52.4	50.9	10.3	76.9	60.3	12.5
	70	98.5	34.9	13.4	154.9	37.3	14.0
	140	143.5	32.7	17.9	159.5	31.2	26.1
				Ste. Rosalie 1988			
Ryegrass	0	76.1		15.0	81.8		15.6
	70	113.2		20.0	97.9		43.9
	140	127.5		103.5	125.4		58.4
Red clover	0	79.4		21.3	97.4		21.1
	70	117.8		37.6	114.2		36.8
	140	132.7		67.0	111.9		96.7
				Ste. Rosalie 1989			
Ryegrass	0	22.0	18.5	10.2	35.2	29.8	12.1
	70	32.1	27.4	12.2	59.7	23.3	40.2
	140	59.8	35.6	44.2	78.1	24.5	33.4
Red clover	0	12.5	32.4	11.9	37.6	24.0	14.0
	70	31.2	24.0	16.7	49.2	30.1	21.3
	140	39.3	38.2	36.2	70.7	30.8	44.5