INTERCROPPING CORN AND SOYBEAN FOR HIGH-PROTEIN SILAGE IN A COOL TEMPERATE REGION

by

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To the memory of my grandfather, Martin M. Bauman (1897 -1960).
In the few years I knew him I felt his sense of fairness,
his encouragement of the unique potential in each of us and
his special respect for our agricultural sustenance.

ABSTRACT

Ph.D. Ralph Martin Plant Science

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The overall hypothesis of this research was that silage biomass and protein yields would be higher in corn-soybean intercrops than in monocrops on the same land area. Yields, European corn borer infestation and N transfer were tested over tall and dwarf corn hybrids, nodulating and nonnodulating soybean genotypes and at 0, 60 and 120 kg N ha^{-1}. Land Equivalent Ratios ranged from 0.97 to 1.23, but most were higher than 1.10. Protein concentrations of corn-soybean silage, up to 10.76%, were on average 9.24% vs. 7.41% in corn silage. A general trend of higher protein yield ha^{-1} in intercrops compared to corn monocrops was significant in 1986. Corn-soybean intercrops at 60 kg N ha^{-1} and three population densities were \$132 to \$261 ha^{-1} more cost effective than monocropped tall corn at 120 kg N ha^{-1}. European corn borer infestation was reduced by intercropping and was higher at 120 kg N ha^{-1} than at 60 or 0 kg N ha^{-1} Under normal rainfall, dwarf corn had higher protein and yield levels when intercropped with nodulating rather than nonnodulating soybean. On N-depleted soil, N transfer was detected from nodulating soybean to nonnodulating soybean and to corn by the ^{15}N dilution method, and to corn by direct ^{15}N labelling of nodulating soybean.

RESUME

INTERCALER LE MAIS AVEC LE SOYA POUR PRODUIRE UN ENSILAGE RICHE EN PROTEINE EN ZONE TEMPEREE

L'hypothèse de départ était que les rendements (biomasse et protéine) seraient plus élevés en cultures intercalaires de soya et maïs, qu'en monocultures. Les rendements d'hybrides de maïs et maïs nain, et de soya nodulant et non-nodulant, cultivés avec 0, 60 ou 120 kg N ha^{-1}, furent évalués, ainsi que le degré d'infestation par la pyrale et le transfert d'azote entre les plantes. Les rapports équivalent terre allaient de 0.97 à 1.23 et, dans la plupart des cas, ils étaient supérieurs à 1.10. La teneur en protéine du fourrage de maïs et soya pouvant atteindre 10.76%, était de 9.24% en moyenne, tandis que celle du maïs seul était de 7.41%. La tendance de la teneur en protéine du maïs intercalé à surpasser celle du maïs en monoculture, fut significative en 1986. Les cultures intercalées, cultivées avec 60 kg ha-1 et à trois densités de population, peuvent permettre des économies de $132 à $261 ha-1 si elles sont substituées à une monoculture de maïs cultivée avec 120 kg N ha-1. L'infestation du maïs par la pyrale qui fut réduite en culture intercalée, était plus importante à 120 kg N ha-1 qu'à 60 ou à 0 kg N ha-1. En condition de précipitation normale, le maïs nain eut une teneur en protéine et un rendement plus élevé quand il était intercalé avec du soja nodulant plutôt que non-nodulant. Dans un sol pauvre en azote, un transfert d'azote du soja nodulant au soya non-nodulant et au maïs, fut mesuré grâce à la méthode de dilution d'^{15}N.

ACKNOWLEDGEMENTS

I appreciate the enthusiasm, curiosity and energy my supervisor, Dr. Donald L. Smith, willingly shared during many discussions about my research and courses. His expeditious and conscientious reviews of each version of every manuscript was very helpful. I am indebted to my supervisor in Ottawa, Dr. Harvey D. Voldeng, for patient and careful consideration of my initial research proposals, continuing inquiries and manuscripts. He generously provided the necessary facilities and technical assistance during the four years of research. I appreciate that Dr. Bruce Coulman and Dr. Angus MacKenzie listened carefully and provided useful suggestions at my graduate committee meetings.

I am thankful for the assistance of many scientists and technicians at Agriculture Canada, in Ottawa. Dr. Robert Hamilton recommended corn hybrids and advised me throughout the research. Dr. Michael Binns offered direction for statistical analysis. Dr. Gary Fulcher and Donald Flynn arranged for me to use their laboratory and Tecator, Kjeltec 1030 Auto Analyzer. I was advised by Dr. Caroline Preston and Dr. Fergus MacDowell and used their equipment for ^{15}N analysis. The proficient technical assistance of Leroy Palmer, Sydney Boubier, Ron Guillemette, Don Leonard and others in the soybean crew was crucial for the completion of this research.

I value the many hours of precise technical work by Sima Khosravi and Stewart Liebovitch and the helpful comments of Chantal Hamel. Rosalie Martin, Katie Brennan and others who helped at harvests made it possible to process many samples at busy times. Barry Denison's cooperation, advice and the access I had to his farm and equipment, in 1987, is much appreciated.

Finally, I offer a bouquet to Elizabeth, who generously encouraged me when I needed it, left me to my work when I needed that and somehow knew the difference. Thank-you!

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Section 1

CONTRIBUTIONS OF CO-AUTHORS TO MANUSCRIPTS FOR PUBLICATION

The contents of sections 3 and 5 are drawn, respectively, from the manuscripts for publication, Martin et al. (1990a) and Martin et al. (1990b). The contents of section 6 are the compilation of the manuscripts for publication by Martin et al. (1990c) and Martin et al. (1990d). These four manuscripts were co-authored by myself, R.C. Martin, my supervisor at Macdonald College, Dr. D.L. Smith and my supervisor at the Plant Research Centre of Agriculture Canada, in Ottawa, Dr. H. D. Voldeng. Dr. Smith and Dr. Voldeng provided normal supervisory guidance from the outset of the research to the reviewing of the manuscripts before submission for publication.

Dr. Voldeng arranged for me to obtain the use of field sites, appropriate field equipment, drying and grinding facilities, laboratories, growth chambers, greenhouse space, storage space, computers and technical assistance at Agriculture Canada, in Ottawa. I performed all tasks and techniques of the research but technicians assisted during the compressed time periods of planting and harvesting plant material. I also received assistance to control weeds and to grind plant samples.

Dr. Smith arranged for technical assistance to do part of the ^{15}N analysis and other assays in his laboratory. As a student, under his auspices, I used computers and other facilities at Macdonald College. We discussed the data which I had statistically analyzed and he offered suggestions for organizing it in manuscripts.

I wrote the first draft of each manuscript for review by both Dr. Smith and Dr. Voldeng. I then wrote the second draft of each one and after minor corrections by both supervisors I submitted the manuscripts for publication.

The manuscript of Martin et al. (1989), included in part, in section 4, was co-authored by Dr. J.T. Arnason, Dr. J.D.H. Lambert and P. Isabelle in addition to Dr. Smith and Dr. Voldeng. The contributions of Dr. Smith and Dr. Voldeng were as descibed previously. Dr. Arnason suggested that we compare European corn borer infestation in the established corn-soybean intercrops and corn monocrops in 1985. Technicians, employed by Dr. Arnason and Dr. Lambert, were assigned to assess the percent infestation in treatments that Dr. Arnason and I had agreed should be tested. I worked with them for part of the assessment in the field. We also tested the same treatments in 1986. Dr. Arnason and his student, P. Isabelle, collated the original infestation data and after preliminary statistical analysis decided it should be published. I revised the analysis of the infestation data and combined it with yield data, previously analyzed, and then wrote the first draft of the manuscript. It was reviewed by Dr. Arnason, Dr. Lambert, Dr. Voldeng and Dr. Smith before I wrote the second draft which Dr. Smith and Dr. Voldeng reviewed a second time prior to submission for publication.

Section 2

GENERAL INTRODUCTION

2.0. Intercropping :

Intercropping is the practice of growing two or more crops in close spatial proximity such that the growth cycles of the component crops overlap in time as well as space. In a relay intercrop a second crop is planted after the first crop has reached its reproductive stage of growth but before it is ready for harvest. A mixed intercrop has no distinct row arrangement but in a row intercrop at least one component crop is planted in rows. A strip intercrop facilitates independent cultivation of each crop in strips but the strips are narrow enough for agronomic interaction of the component crops (Francis, 1986; Willey, 1979; Andrews and Kassam, 1976; Sanchez, 1976).

Intercropping has been practiced in the tropics for centuries and it is still common there. Although of less importance in temperate regions, intercropping, especially with corn (<u>Zea</u> <u>mays</u> L.), beans and squash, was a tradition of North American Indians (Plucknett & Smith, 1986).

> "Historically, intercropping has been regarded as a primitive practice which would give way to sole cropping as a natural and inevitable consequence of agricultural development. . . . Now, there is a growing appreciation of the need for some research emphasis specifically on intercropping. The continuing importance of intercropping in farming practice would alone justify this emphasis, but an equally valid reason is the possibility that intercropping can provide yield advantages compared to sole cropping" (Willey, 1979).

Many Third World farmers base their cropping decisions on the return of financial and labour inputs. Gross monetary returns of crop mixtures were 62% higher than sole crops on a land area basis in Nigeria. The return on labour input, most limiting during June and July, was 26% higher for intercrops than for monocrops (Norman, 1971).

The compensatory potential of intercrops may result in greater yield stability (Willey, 1979) but this argument is countered by concerns that a low-yielding or non-yielding component crop can excessively stress a more valuable component crop (Harwood and Price, 1976). It was more probable that bean-maize intercrops in Columbia would provide a farmer with a steady income than either maize or bean monocrops, although the higher risk bean monocrop was potentially more lucrative (Francis and Sanders, 1978).

An important phenomenom in intercropping systems is nitrogen fixation in legumes. Breeding and selecting for this capacity within a stressed intercropping environment can augment the potential of an intercrop. Putnam et al. (1986) noted increases of 11 - 51% in crude protein concentrations of corn-soybean (Glycine max [L.] Merr.) intercrops compared to corn monocrops. Nitrogen fixation by beans was only slightly affected in a mixture with maize which did not reduce bean plant weights until N fixation was negligible (Graham and Rosas, 1978). Nodulation was more extensive on beans intercropped with corn than on monocropped beans (Boucher and Espinosa, 1982). Although light transmitted through a maize canopy was only 67% of that available to sole cropped groundnut, N fixation was not affected in one trial but it was reduced in other intercrops with maize, millet or sorghum (Nambiar et al. 1978). The proportion of fixed N in alfalfa increased significantly in mixtures with timothy compared to pure stands but the absolute amount of fixed N in alfalfa decreased in mixtures (Ta and

Faris, 1987). They also reported N transfer from alfalfa to timothy.

A broad view of intercropping value, of some relevance to those concerned about environmental degradation due to monocropping, was given by Igbozurike (1971):

> "Since humans have not yet advanced to the point of evolving a totally new and well-adjusted ecosystem they have to follow closely on nature's heels. This is precisely what mixed cropping does. Although it is not a perfect replication of nature its environmental rationle is infinitely superior to that of monoculture."

Plant species have different morphological and physiological characteristics which allow them to occupy different ecological niches There are differences in the timing of resource interception, the location of resource interception, the rate of absorption, the rate of growth and the response of yield to variation in the level of resource availability. Trenbath (1986), proposes that these differences permit a better absorption and conversion of light, water and nutrients to biomass by intercrops than by monocrops.

Intercropping does include several disadvantages. The most obvious is that of direct competition for the limiting resources of light, water and nutrients. Donald (1963) stated that :

> "Competition occurs when each of two or more organisms seeks the measure it wants of any particular factor or thing and when the immediate supply of the factor or thing is below the combined demand of the organisms".

Donald (1958) reported that competition for both light and nitrogen increased the detrimental effects to the dominated plant beyond the additive effects of the two factors. Allelopathy can also impede the growth of an associated crop (Rice, 1984).

The primary restriction to intercropping in modern agriculture may well be the lack of appropriate machinery to plant and harvest two or more crops in close spacial arrangements at the same or at different times. In Canada, an operation is expensive if it impinges on a farmer's brief allotted time to plant and harvest crops on either side of a short growing season. There is also the problem of herbicide, pesticide and fertilizer compatibility for two or more crops with different requirements (Willey, 1979).

2.1 Nitrogen transfer in intercrops :

Broadbent et al. (1982) noted extensive transfer of fixed N_2 from clover to ryegrass with as much as 80% of the total N in associated ryegrass derived from atmospheric N after several months in a mixed sward. Decomposing clover nodules may have been the major source of transferred N. Nitrogen transfer from alfalfa to associated timothy contributed up to 22% in the first year and 30% in the second year of the total timothy N yield with amounts as high as 13 kg N ha^{-1} (Ta and Faris, 1987).

Eaglesham et al. (1981) reported a higher N content and a significant dilution of ^{15}N in intercropped maize compared to monocropped maize. It was assumed that the extra nitrogen in intercropped maize was transferred from cowpea. They concluded that nitrogen excretion by an intercropped legume gives significant benefit to the associated crop only in conditions of low soil mineral N status. Patra et al. (1986) found that cowpea contributed 16 to 32% of the total N uptake of intercropped maize in greenhouse trials and cowpea contributed 28% or 21.2 kg N ha^{-1} in field trials. In a split root experiment, van Kessel et al. (1985), showed that ^{15}N added to a partial soybean root system in one pot could be detected in a corn shoot in an adjacent pot with the other part of the soybean root system. However, van Kessel and Roskoski (1988) were unable to detect nitrogen transfer from cowpea to maize in the field when using the ^{15}N dilution method.

Elmore and Jacobs (1986), using the difference method, attributed an increased sorghum N yield to transfer of nitrogen from nodulated soybean. A lower sorghum N yield was observed in a sorghum-nonnodulating soybean intercrop. They assumed that nodulating and nonnodulating isolines used soil-N equally. Talbott et al. (1985), showed that six nodulating genotypes and one nonnodulating genotype utilized soil-N equally.

Vest (1971) demonstrated that a nonnodulating soybean variety had improved yield, protein, seed weight and seed number when grown with an actively nodulating variety. Vasilas and Ham (1985) could not measure increased yields of nonnodulating soybeans grown with nodulating soybeans but nitrogen transfer was evident based on the diluted ^{15}N fertilizer concentration in intercropped vs. monocropped nonnodulating soybeans. Burton et al. (1983), found that a nonnodulating soybean cultivar had an average 38% yield increase and a 56% total protein increase when it was grown with each of six nodulating cultivars rather than as a monocrop. These increases were even higher in association with its nodulating isoline.

2.2. Evaluation of intercrop yields :

Intercrop yields are often evaluated by a Land Equivalent Ratio (LER) which is mathematically equal to the Relative Yield Total (RYT) developed by De Wit and Van Den Bergh (1965). RYT has been used for plant competiton studies on a yield basis whereas LER is an evaluation of intercropping efficiency on a land-area basis (Willey, 1979). LER = $L_a + L_b = Ya^i/Ya^m + Yb^i/Yb^m$ where Y^i/Y^m is a component crop ratio of an intercrop yield on a given land area over a monocrop yield on the same land area. An LER represents "the ratio of the land area required under monocropping to one of intercropping at the same management level to produce an equal amount of yield" (Francis, 1986).

Hiebsch and McCollum (1987a), argued that LERs are inadequate because they do not account for the biological efficiency of an intercrop in an exact period of time. An Area x Time Equivalency Ratio (ATER) was therefore proposed where ATER = $[(Ya^i/Ya^m)(ta^m) + (Yb^i/Yb^m)(tb^m)] / (t^i)$ and where t^m is the duration of the production cycle in monoculture for each component crop and t^i is the duration of the intercrop system. In their example, an LER is 1.2 and the corresponding ATER is 1.0 for 135 day corn and 90 day beans in an intercrop system where Y $corn^i = 3$, Y $corn^m = 5$, Y $bean^i = 0.6$ and Y $bean^m = 1$. ATERs are not different than LERS when both component crops are planted and harvested at the same times.

Reddy (1987), criticized the ATER approach on the basis that unless another complete monocrop of beans can be grown on an equivalent land area it does not make biological sense to minimize the advantage of an LER by supposing that a partial sole crop of beans could have been grown. In their rebuttal, Heibsch and McCollum (1987b), contended that an ATER is useful even if not necessarily practical, because it can distinguish between biological efficiency and prolonged exposure to environmental growth factors at the same efficiency. The implications of ascertaining whether practical agricultural advantage is achieved in intercrops because of increased conversion efficiency or because of prolonged exposure to environmental growth factors, could be significant in the selection of optimum component crop genotypes.

Hiebsch and McCollum (1987a), in summarizing 182 ATERS of corn-legume mixtures said that the average ATER on low-N soil was 1.3, on medium-N soil it was 1.1 and on high-N soil it was 1.04, whereas 393 intercrops excluding legume-nonlegume mixtures had an average ATER of 1.0, with a distribution approaching normality. They attributed intercropping advantage in legume-nonlegume mixtures to N fixation with this being proposed as the only set of conditions which can really increase yields per day. Wade and Sanchez (1984) relay intercropped tall crops of corn and cassava in one m rows with soybean and cowpea in the first year and with upland rice, peanut and cowpea in the second year to achieve ATERs of 1.3.

Mead (1986) reviewed several indices of intercropping biological advantage. They are based on the LER ratios L_a and L_b which respectively represent the fractions of intercrop 'a' yield divided by monocrop 'a' yield and intercrop 'b' yield divided by monocrop 'b' yield. It is important to remember that L_a and L_b are ratios, the divisors being monocrop yields which influence the ratio as much as the intercrop yields. Each ratio should include acceptable rather than unusually low monocrop yields which inflate L_a or L_b. The relative crowding coefficient developed by De Wit (1960) was defined by Mead (1986) as $L_a/(1-L_a) \times L_b/(1-L_b)$. The aggressivity coefficient of McGilchrist and Trenbath (1971) was defined by Mead (1986) as $L_a - L_b$ without including the proportions of the component crops. Similarily, the competition ratio (Willey and Rao, 1980) was defined as L_a / L_b by Mead (1986).

In some cases a reduced intercrop yield of the main crop may not be acceptable to a farmer. Underseeded forages in corn may be for soil conditioning purposes only with no expectation of harvestable forage yield. The L_a ratio for corn should then be equal to or greater than one unless a farmer is willing to accept reduced soil degradation as compensation for an L_a less than one.

2.3. The corn crop :

Corn (Zea mays L.) production exceeds 400 million t yr^{-1} in the world, somewhat less than wheat at close to 500 million t yr^{-1}, but more than rice which is near the 400 million t yr^{-1} production level (Hallauer, 1987). Animals are fed more than 100 million t of grain corn in the USA and an additional 130 million t of whole plant silage is consumed by ruminants (Perry, 1988). Over 90% of corn grown in developed countries is fed to livestock. In the USA annual production has been more than 200 million t for the last ten years, and 80% of this was from 12 states in the Corn Belt (Benson and Pearce, 1987). Corn yields in the USA increased from 1300 kg ha^{-1} in 1930 to about 7500 kg ha^{-1} in 1985 (Hallauer et al. 1988).

In Ontario, from 1983 to 1988, grain corn was grown on an average of 784,000 ha and silage corn was grown on an average of 194,000 ha. During the same period the farm value of grain corn averaged $ 596,000,000 yr^{-1} and silage corn averaged $130,000,000 yr^{-1}. In Eastern Ontario, in 1988, grain corn had a farm value of $59,694,000 on 69,400 ha and silage corn was worth $25,536,000 on 34,200 ha (Ont. Minis. Agric. Food, 1988).

Total economic costs of corn production in the USA from 1981 to 1983 were consistently high enough to result in negative residual returns (in USA \$, -\$60 to -\$112 ha^{-1}) to management and risk. The net returns to owned inputs during the same period were (in USA \$) \$123 to \$174 ha^{-1} (Leath and Hill, 1987).

Corn has more metabolizable energy or total digestible nutrients than other feed grains because of its high starch and low fibre content. This highly concentrated energy source also contains higher amounts of B-carotene (pro-vitamin A) and xanthophylls than other feeds (Perry, 1988). *Opaque*-2 corn was found to have higher lysine contents than the usual low levels in corn (Mertz et al. 1964) but yields have been lower, moisture levels higher and kernel damage more extensive than in comparable dent or flint types (Alexander, 1988). Steers fed *opaque*-2 corn silage gained less than on normal corn silage which had more digestible energy (Thomas et al. 1975) but some hog farmers have had better results with *opaque*-2 grain corn (Alexander, 1988).

Corn as a C_4 tropical plant, with low photorespiration can fix more carbon at higher temperatures than C_3 plants and transpire less water per unit of biomass. Nevertheless, corn can be grown as far as 50°N in Canada as well as in the tropics and it is produced from semiarid regions of 25 cm annual rainfall to regions with more than 400 cm rain yr^{-1} (Stoskopf, 1985). Corn has also adapted to altitudes from sea level to 3600 m and growing seasons from 42 to 400 days (Benson and Pearce, 1987).

In Ontario, suitable corn hybrids are recommended for a Corn Heat Unit (CHU) (Brown, 1981) range of 2400 (2200 for silage) to .500. Corn should be planted before May 15 in Eastern Ont. and yield losses of 40 kg ha^{-1} day^{-1} can be incurred if planting is delayed beyond that date.

If the soil temperature is less than 10° C corn plants will not germinate and emerge from the soil. The growing point may remain underground for three to four weeks thereby preventing irreversible frost damage (Upfold and Morris, 1987). Moisture stress caused the greatest yield reduction in a corn crop in the days just after silking (Shaw, 1988) and kernel weights tended to be lowest under moisture stress 12 to 16 days after silking (Grant et al. 1989).

Row widths for corn appear to be optimal at about 76 cm where yields are 5% higher than at 96 to 102 cm. Grain yields were not affected by decreasing row widths from 76 cm to 38 cm but yields were lower in twin rows which were 1.52 m apart (Ottman and Welch, 1989). Bullock et al. (1988) found that equidistant plant spacing patterns improved corn yields over conventionally spaced corn in rows. They concluded that early season growth rates and leaf area indexes (LAI) were most favourably affected by the equidistant planting, resulting in the final yield advantage. Ottman and Welch (1989) reported that some radiation interception was shifted to lower leaves from upper leaves in wide (1.52 m) twin rows (13 cm between twin rows) but then more radiation struck the soil, yield was decreased and nutrient concentrations were no different than in narrower rows. An average corn grain yield increase of 640 kg ha^{-1} was reported by Karlen and Camp (1985) in twin rows, (35 cm apart with 96 or 112 cm between pairs of rows) compared to single rows 96 cm apart.

Corn plant population densities for optimum production tend to increase as corn is planted further north (Olson and Sander, 1988). Final plant stands of 52,000 to 58,000 plants ha^{-1} are common in Ontario but under stress-free conditions 67,000 plants ha^{-1} are acceptable. Silage yield is not as adversely affected by lodging from high populations of 60,000 to 70,000 plants ha^{-1} (Upfold and Morris, 1987). Near Elora, Ontario, interception of photosynthetically active radiation by corn was 9% larger at an LAI of 4.8 with 100,000 plants ha^{-1} than at an LAI of 2.0 with 39,000 plants ha^{-1} (Tollenaar and Bruulsema, 1988). The LAI of corn plants increased from 1.7 to 4 0 as plant population densities increased from 19,000 to 63,000 plants ha^{-1} and by 35 days after planting 75% of incident light was intercepted at 63,000 plants ha^{-1} (Tetio-Kagho and Gardner, 1988a). Total plant biomass increased asymptotically to populations of 125,000 plants ha^{-1} but grain yields peaked at 100,000 plants ha^{-1} and declined thereafter (Tetio-Kagho and Gardner, 1988b).

2.3.1 Origin and evolution of corn :

Corn is a monocotyledonous plant in the tribe Maydeae of the grass family. Two genera of Maydeae, Zea and Tripsacum are native to the western hemisphere and five genera are native to Asia. There are four teosinte species in the Zea genus; the annuals, Z. mexicanus and Z luxurians, and the perennials, Z. perennis and Z. diploperennis. All teosintes have a chromosome number of 2n = 20 except Z. perennis, which is 2n = 40. Zea mays has a chromosome number of 2n = 20 as well and is more easily crossed with teosinte species than those of the genera Tripsacum which has chromosome numbers that are multiples of 18 (Hallauer, 1987).

Manglesdorf (1986) postulated that Zea mays and annual teosintes were descended from crosses of a primitive pod-popcorn and Z. diploperennis. He had originally thought that Zea mays and annual teosintes were from crosses of primitive pod-popcorn and Tripsacum (Manglesdorf and Reeves, 1939). Galinat (1988) argues that Zea mays was developed over time by human selection (possibly inadvertent) of teosinte and then by further deliberate human selection of those plants with corn ears rather than the spike of teosinte. His argument is based on the fact that teosinte is probably older but not cytogenetically different from Zea mays and that the cob of modern corn is only possible as an artifact of domestication. The variability in open-pollinated teosinte could be self generating. However, Mangelsdorf (1986) insists that corn is older than teosinte and that corn inherited its cob features from a wild parent.

2.3.2 Some corn breeding objectives :

Corn is a monoecious plant, with natural cross-pollination of more than 99%. Twenty five million pollen grains plant^{-1} can be produced resulting in a range of 500 to 1200 kernels plant^{-1}. Therefore, corn is easily manipulated to develop preferred crosses and with such a large number of seeds produced from each cross, the return is high for breeding inputs (Hallauer, 1987 and Zuber and Darrah, 1987).

American Indians developed races of corn for thousands of years and had about 250 to 300 races by the time Europeans settled in North America. The dents of the USA Corn Belt were started about 1850 from crosses of northeastern flints and southern dents. (Hallauer, 1987 and Hallauer et al. 1988).

Pure inbred line development with the pedigree selection method was initiated by Shull (1909). He found that an inbred, Strain A, produced

5.4 kg and an inbred, Strain B, produced 5.9 kg but a cross yielded 21.8 kg and the reciprocal cross yielded 24.9 kg. It is assumed that all weights apply to a standard plot area which was not given. Inbreds were too low-yielding to commercially produce hybrid seed from single crosses according to Jones and Mangelsdorf (1926). They recommended double crosses to improve vigour, although they recognized that uniformity had been partially compromised. Subsequently, the use of hybrids on farms in the USA increased from 1% of the corn acreage in 1933 to 90% in 1945. Since the 1960s, improved elite inbred lines from recurrent selection have made single-cross hybrid seed more available. Farmers prefer the resulting corn plant uniformity and the higher yields (Zuber and Darrah, 1987).

Detassling of the female parent in crosses was largely replaced by inbreds with the Texas cytoplasmic male sterility (cms) gene. After the 1970 epidemic of southern leaf blight due to susceptibility of corn with cms genes, some detassling was resumed. Recently, hybrids have included seeds from cms and restorer systems blended with seeds produced by detassling (Wych, 1988). In the 1970s and 1980s over 85% of corn breeding has included elite inbred lines as parents of breeding populations (Hallauer, 1987).

The major emphasis of corn breeding has been to improve yields. That goal has been more readily attained by not selecting for other traits. It is anticipated that yield increases will continue since quantitative genetic studies have indicated there is considerable additive genetic variability to enable progress. Pest resistance and maturity will probably become increasingly important due to expansion into regions with shorter growing seasons, conservation tillage and multiple cropping practices (Hallauer, 1987).

Stalk rot is the most serious corn disease and plant breeders have worked hard to solve the problem. High nitrogen levels in combination with inadequate potassium levels also contribute to stalk rot. It has not been possible to establish control plots completely free of the disease and furthermore, inoculation, which may not duplicate natural stalk rot conditions can be confounded with natural infection (Smith and White, 1988). Devey and Russell (1983) found that stalk rot infections decreased and mechanical stalk strength increased but that yields declined by 40% over seven cycles of selection. In Ontario, stalk rot is the primary disease problem (Upfold and Morris, 1987) and resulted in an average 13% stalk breakage of all hybrids in the 2500 to 2700 CHU range in 1983 and 1984 (Ont. Corn Comm., 1985).

It is also necessary to breed for resistance to, or at least to avoid susceptibility to ear molds, eyespot, anthracnose, smut and northern leaf blight in Ontario (Upfold and Morris, 1987).

European corn borer, <u>Ostrinia</u> <u>nubilalis</u> (Hubner), one of the most important corn insects in North America, was first reported in Ontario, in 1920. It has been possible to breed corn for resistance to the first-generation strain (Dicke and Guthrie, 1988) which is most common although not exclusive in Eastern Ontario and Quebec (M. Hudon, Agric. Canada, pers. comm.). It has been difficult to breed for resistance to the second-generation strain as well as the first-generation strain without unacceptable yield reductions, because only two or three of twelve genes are common to resistance in both strains (Guthrie, 1987). Corn plants become more susceptible to disease organisms when injured by European corn borer (Hudon et al. 1982). In Ontario, to control lodging of stalks weakened by European corn borer, hybrids with good standability are recommended (Upfold and Morris, 1987). Raemisch and Walgenbach (1983) found that infestation by first-generation European corn borer reduced silage yields by 14.1 to 14.7% compared with plots treated with cypermethrin. One European corn borer cavity $plant^{-1}$ reduced corn grain yields by 102 to 466 kg ha^{-1} (Umeozor et al. 1985). In Quebec, Boivin et al. (1988) found no correlation between percentage of plants infected and yield, although they noted that hand harvesting minimized potential stalk breakage and ear drop losses.

Other insects to which hybrids in eastern Ontario should be as resistant as possible are northern corn rootworms, potato stem borers, cutworms and corn leaf aphids (Upfold and Morris, 1987).

The Illinois corn breeding experiment showed that corn oil content, usually at 4 to 5%, was at a low of 1.2% and a high of 21.3% after 87 generations of selection for each of low and high oil concentrations (Dudley, J.W., pers. comm. in Alexander, 1988). There is additive variance in corn for this trait. Similarly, low and high protein levels were realized. After 70 generations of selection corn originally at 10.9% protein was up to 26.6% in the high protein selection and as low as 4.4% in the low protein selection (Dudley et al. 1974). It was also found that, within the range of 8 to 11%, grain corn protein was not necessarily related inversely to yields. Percent protein was raised to the range of 11 to 12% without yield reductions (Dudley, J.W., pers. comm. in Alexander, 1988).

2.3.3 Corn in cropping systems :

Corn has been grown in rotation with oat, wheat, barley, soybean, grain sorghum, alfalfa, clover, grasses, combinations of these crops and other crops (Benson and Pearce, 1987). Corn rotated with soybean, oat and clover, and sorghum yielded an average 2100 kg ha^{-1} more grain than continuously monocropped corn. Corn grain yields responded to no more than 90 kg N ha^{-1} after a legume in rotation but required 180 kg N ha^{-1} for the same maximum yields after continuous corn. Peterson and Varvel (1989b) also noted higher corn yields in a four year rotation where corn was limited to one of the four years, than corn in a two year rotation with soybean.

Crookston et al. (1988) found that soybean and fallow (with or without TRIA, a compound of soybean residue potentially favourable to the growth and yield of corn) were equally effective in improving corn yields compared to continuous corn monoculture. They concluded that the yield advantage was due to the absence of some negative effect from continuous corn monoculture.

> "In monoculture, a group of microorganisms tends to develop that exude phytotoxic substances deleterious to the crop. The addition of a green manure crop such as rye before corn removes the supressive root excretions and changes the soil microbial population that is damaging to corn in monoculture" (Olson and Sander, 1988).

Crookston and Kurle (1989) reported that rotating soybean with corn increased corn yields compared to continuously monocropped corn. However, the removal of above-ground corn residue did not affect continuous corn monoculture yields. Similarly, the addition of corn residue to soybean plots had no effect on the yield of corn in the following year. Grain yields of corn with intercrops or cover crops of various clovers, alfalfa, trefoil, two pea cultivars, vetch, cowpea, annual and perennial ryegrass, rye, oat, buckwheat and wheat were not different than monocropped corn yields with or without 90 kg ha^{-1} of sidedressed N. A starter fertilizer of 17 kg N ha^{-1} had been applied to monocropped corn and 90 kg N ha^{-1} was applied as a sidedressing to each cover crop. In the second year, corn following the same cover crop treatments with no additional applied N, resulted in corn yields about the same as continuously monocropped corn sidedressed with 90 kg N ha^{-1} in the first year and no sidedressed N in the second year. In a related third experiment, corn grain yields were higher in cover crop treatments on a four year average than in continuously monocropped corn without sidedressed N over the same period. The associated crops were medium red clover, mammoth red clover, white clover and medium red clover mixed with annual ryegrass. However, only the medium red clover treatment matched the control treatment given 17 kg N ha^{-1} each year. Treatments with rye or annual ryegrass had grain corn yields lower than the control without sidedressed N (Scott et al. 1987).

Crimson clover and hairy vetch cover crops established the previous fall and dessicated in the spring provided substantial N to increase grain corn yields compared to corn after cover crops of rye or fallow treatments without applied N. In some cases the legume cover crops maintained grain corn yields at the same levels of fallow and rye treatments with 100 or 200 kg N ha^{-1}. The yield effects of early or late dessication and early or late planting were variable but the overall yield effect of these dates was negligible compared to the cover crop type (Wagger, 1989).

In Quebec, intercropping with a forage legume mixture of alfalfa, vetch and red clover either depressed or did not affect corn grain yields compared to monocropped corn yields, regardless of N levels. Intercropped corn was at 40,000 plants ha^{-1} compared to 80,000 plants ha^{-1} in monocropped corn. Nevertheless, inorganic soil N levels were also depressed by the intercrops at one site, an indication of legume competition for soil N (Tomar et al. 1988).

A comprehensive account of all cropping systems to which corn has been adapted would be too long. Therefore, only a few more examples are briefly noted. Corn has been intercropped with ratoon sugar cane in Mauritius where LERs, calculated for three corn monocrops in one period of a ratoon cane crop, were sometimes greater than one (Govinden, 1985). A modern corn hybrid was less suitable under a shifting agriculture system than a local black corn variety in Belize, which removed fewer soil nutrients and was less prone to weevil attack (Lambert and Arnason, 1982). Mulongoy and van der Meersch (1988) recorded corn yields, improved by 104%, with the application of Leucaena leucocephala prunings in an alley cropping system compared to corn yields when the prunings were removed from the system. Corn has also been a component crop in double cropping, triple cropping and quadruple cropping in long growing season regions (Sanchez, 1976). An unusual example to many, is the report of double cropping corn in Mexico, after "quelites" (food weeds) such as Amaranthus retroflexus (pig weed), Lepidium virginicum (pepper grass) and Chenopodium album (lamb's quarters) because of the stimulatory effect of the quelites on corn seedling growth (Kahl, 1987).

2.4. The soybean crop :

Soybean (Glycine Max [L.] Merr.) has been gaining importance in Ontario and the world. In Ontario, soybean was first introduced as a hay crop in 1893. Soy oil extraction in Ontario since World War II, has contributed to increased land use for soybean from 18,000 ha in

1945 to 450,000 ha with yields of 2.8 t ha^{-1} in 1988. Domestic requirements are for 500,000 hectares (Upfold and Olechowski, 1988) In Europe, soybean had been used as an oilseed since 1900. Soy oil was first processed in the USA in 1911 and by 1917 cottonseed oil mills were contracting for soybean crops (Smith and Huyser, 1987). Thatcher (1925) noted a 26-fold increase in Ohio soybean production from 1916 to 1923, mostly by the displacement of oats. The USA produced 62 million t of the world production of 95 million t in 1983. The soybean proportion of world oilseed production is now greater than 50% and soybean meal is 70 to 75% of global high protein meal (Smith and Huyser, 1987).

Soybean requires at least 2400 Corn Heat Units (CHU) (Brown, 1981) in one growing season. Temperature is usually the limiting climatic factor in Eastern Ontario but inadequate moisture can be a problem and short photoperiod requirements exclude many varieties. The planting date should be between May 10 and May 25 when the soil reaches 10 ^{o}C, although soybean can briefly survive a temperature of -2.8 ^{o}C. Some cultivars reach maturity even if planted later and lodging may be reduced by delayed planting (Upfold and Olechowski, 1988).

Narrow row widths seem to have more beneficial effects as soybean is planted further north. To achieve maximum yields, the leaf canopy should intercept all light between the rows as the reproductive stage is reached (Tanner and Hume, 1978). Row widths of 50 cm in Southern Ontario to 18 cm in Eastern Ontario are recommended for high yields (Upfold and Olechowski, 1988).

Population density can vary considerably with only marginal yield effects. Stand reductions of 60% decreased soybean grain yields by 25%

(Pepper and Walker, 1988). Low plant densities may result in more pods developing close to the ground and thereby increase harvest losses. Sometimes densely planted seeds in wider rows collectively push through crusted soil more effectively than is possible by more sparsely spaced seeds. The recommended seeding rate in Ontario, is 400,000 to 500,000 ha^{-1} (Upfold and Olechowski, 1988).

2.4.1 Origins and evolution of soybean :

The cultivated soybean, Glycine Max (L.) Merr. and its wild counterpart, G. soja., are now classified as species of the subgenus Soja. G. max, G. soja and most of the species of the subgenus Glycine are diploid ($2n = 40$) (Hymowitz and Singh, 1987). The subgenus Soja and the subgenus Glycine both are part of the genus Glycine Willd. Glycine Willd belongs to the subtribe Glycininae of the tribe, Phaseoleae. The tribe Phaseoleae belongs to the subfamily Papilionideae of the family, Leguminosae (Hymowitz and Newell, 1981). The 13,000 member Leguminosae family is the third largest, next to the Compositae and Orchidaceae families (Stern, 1979).

Soybean was first domesticated in China from the 11th to the 7th century B.C. as understood by pictographic evidence of the ancient Chinese word "shu". The wild annual soybean G. soja is the ancestor of G. max. It has been crossed to G. tomentella, a wild perennial relative of the subgenus Glycine. G. tomentella and G. tabacina, both perennials, overlap geographically with G. soja and are thought to be the closest relatives of G. max from the subgenus Glycine (Hymowitz and Newell, 1981; Hymowitz and Singh, 1987).

2.4.2 Soybean breeding objectives :

The soybean flower has two whorls of stamens which fuse into one whorl of nine elevated stamens around the pistil. Pollen falls directly onto the stigma within the bud, limiting natural crossing to < 0.5 - 1 % (Carlson and Lersten, 1987).

High seed yield has been the primary objective. Seed yield increases of 15.1 kg ha^{-1} yr^{-1} or a 0.6% increase yr^{-1} have been realized. The rate has been decreasing and it is more difficult now to find parents of diverse origin. However, best results are still being achieved from crosses of high yielding cultivars (Fehr, 1978 and 1987)

Diseases account for much of current yield limitations, losses being about 19% $year^{-1}$. (Wilcox, 1983). Breeding has tended to favour specific resistance controlled by major genes. General or field resistance, more quantitative in character, provides horizontal protection but it is more difficult to breed into a genotype. Tolerance to an infection involves selection of the least affected cultivar at a given infection level (Fehr, 1987).

Soybean disease-resistant cultivars have been released quickly following pathogenic difficulties when breeders have anticipated the problems. For example, new races of phytophthora rot occured in Ohio in 1972 and the resistant cultivar Vickery was available by 1978. Soybean breeders and pathologists have agreed to use different sources of resistance to phytophthora rot to be prepared for resistance to new races which may occur. There may be problems in the future with phytophthora rot or other pathogens if private breeders do not continue to work with plant pathologists (Wilcox, 1983). Race 25 is now known to be virulent to the multi-race resistant gene, Rps_1^k. Breeding for multiple gene combinations has been recommended to prolong the time of cultivar resistance (Schmitthenner, 1988).

Maturity of soybean is controlled by major genes but there is also a quantitative component to inheritance. The critical photoperiod decreases from Maturity Group 000 in the north to Maturity Group X in the south (Fehr, 1987). Combined photo-thermal responses are specific to zones of about 4° latitude in North America and outside this range plants fail to mature before the first frost in the north or flower and mature too early in the south (Summerfield et al., 1986). In China, soybeans are developed for seasons less than 90 days (Maturity Group 000) in Heilongjiang Province as well as for long frost-free seasons in the Yangtze River Valley (Maturity Groups VI-VII) where double and even triple cropping is practiced (Wang, 1986). The recessive allele, e4, confers insensitivity to long daylengths and can be used to reduce the negative effect of long days on maturity in northern regions (Buzzell and Voldeng, 1980).

Lodging, rated from erect plants (1) to prostrate plants (5), can cause yield reductions with scores greater than 2.1. Cultivars of indeterminate growth habit are more prone to lodging and taller plants may lodge sooner (Fehr, 1987). Semidwarf soybean cultivars have been developed to counteract the yield barrier of lodging. These cultivars (eg. Elf) are poorly adapted to low-yield environments, require higher seeding rates in narrow rows and are more susceptible to drought early in the season. However, in high-yield environments semidwarf cultivars have a higher yield potential which has been frequently realized (Cooper, 1985).

Drought can cause 25 to 40% of yield loss potential. Indices of drought resistance include root depth and root growth rate, plant water potential and stomatal conductance, stem dry weight and seed yield under conditions of varying water availability. The effects of the mechanisms can be confounded and the best screening method may still be to select for yield among cultivars subjected to various degrees and timings of drought stress (Myers et al., 1986).

A seed quality criterion is to decrease the 9% linolenic acid in soy oil to prevent instability of soy oil to oxidation (Snyder and Kwon, 1987). A cultivar of 4% linolenic acid in the oil has been obtained but this oil has yet to be proven superior (Hammond and Fehr, 1984).

Seed quality can be judged for ability to germinate and lack of shrunken, discoloured or broken seeds. Selection may also occur for shattering resistance, and resistance to herbicide injury and mineral deficiencies (Fehr, 1987).

There has been less selection than might be expected for protein concentration or oil quality since soybean is generally sold by weight and not by seed composition (Fehr, 1987). Protein concentrations of 52% in several accessions in the USA germplasm collection were negatively correlated with yield (Wilcox, 1986).

2.4.3 Problems with trypsin inhibitor and linolenic acid in soybean :

The trypsin inhibitor proteins in soybean seeds can cause growth retardation and an enlarged or hypertrophic pancreas in young animals Trypsin levels in the small intestine are regulated by the hormone, cholecystokinin, which either signals for more or less trypsin. Trypsin inhibitor blocks this control system by complexing with trypsin, and the pancreas by default is signalled to produce more and more trypsin. Thus the pancreas becomes enlarged and trypsin, rich in sulfer containing amino acids, is expelled in the feces causing methionine and cystine deficencies. The trypsin inhibitor effect can be overcome in soy meal or in soybeans by steam heating or toasting for less than 15 min. at 100^{oC}. Longer periods can induce lysine loss (Rackis, 1973 and Snyder and Kwon, 1987).

The essential fatty acids of soybean seed lipids are polyunsaturated and therefore soy oil and soy oil products are considered to lower blood cholesterol levels. However, autoxidation of highly unsaturated soy oil with molecular oxygen causes films and off-flavour in the oil. Hydrogenation with a nickel catalyst increases oxidative stablity of the oil by adding H_2 to the double bonds of the unsaturated fatty acids. Hydrogenation is more selective for linolenic acid which is intended to be eliminated while retaining as much linoleic and oleic acids as possible. The hydroperoxides produced by autoxidation, especially of linolenic acid, can break down further (soybean oil reversion) causing off-flavour even at low peroxide levels. Isomers with higher melting points are formed as hydrogenation saturates double bond positions and double bond positions are shifted from the cis forms to the trans forms. Feeding trials with rats and swine have shown no effect on growth, longevity or reproduction due to trans fatty acids (Snyder and Kwon, 1987).

2.4.4 Soybean in cropping systems :

Soybean was originally grown for hay in North America to feed dairy cattle, beef cattle, sheep and even as a chopped hay supplement for swine and poultry. It was also common to pasture soybean (Morrison, 1959).

In recent years soybean has been a valuable rotation crop although this legume as a monocrop does not appear to increase soil N levels (Johnson et al. 1975). Rotations of soybean with corn, spring grains and wheat can control many problems with pathogens by interrupting their life cycles. This is especially true of phytophthora and rhizoctonia root rots in Ontario (Upfold and Olechowski, 1988). Eight two-year rotation cycles were compared in Louisiana over a period of four years or two complete cycles. Soybean grown after sorghum grain or fallow yielded significantly higher in every comparison with soybean grown after soybean. A ryegrass winter cover crop had little effect on yields. The superior control of soybean cyst nematode by crop rotation was considered to be the cause of higher soybean yields in rotation (Dabney et al., 1988).

Soybean yield, dry matter and seed size were greater in rotations with corn or sorghum than in continuous monoculture. Soybean following sorghum produced higher yields than soybean following corn possibly because fertilizer N was immobilized to a greater extent after sorghum and was more available to soybean later, during pod fill and seed development stages (Peterson and Varvel, 1989a).

Double cropping is practiced most often by planting soybean after winter wheat is harvested and sometimes after vegetable crops, corn or a first-cut forage crop. Wheat straw contains a phytotoxin that may retard initial soybean growth, but the straw can be burned to reduce this phytotoxic effect and to destroy weeds and surface weed seeds. The straw can also be chopped, baled and removed, or plowed under. In the summer, after a wheat harvest, the lack of moisture may inhibit soybean germination and emergence. It may then be necessary to leave straw on the field, as a mulch, to conserve moisture. Soybean has also been grown after soybean in the southern USA, but intensive management is required (Johnson, 1987 and Tanner and Hume, 1978).

Relay intercropping soybean into wheat before the wheat is harvested has resulted in wheat-soybean combinations moving further north than was possible under strict double cropping conditions. Intercropping soybean into winter wheat or spring oats in Illinois did not affect the cereal yields but soybean yields were decreased to between 7 and 93% of monocrop yields. Soybean aerially seeded did not establish stands due to lack of moisture (Chan et al., 1980). Under relay intercropping and monocropping conditions of soybean with winter wheat or spring oats, genotype x environment interactions were not found for soybean yield. Therefore, a separate breeding program for soybean to be relay intercropped was not recommended (McBroom et al., 1981). In Missouri, wheat yields were reduced between 16 and 23% in a wheat-soybean relay intercrop and wheat yields declined as drilling into 20 cm rows was progressively delayed beyond the early jointing stage of wheat. Intercropped soybean yields were 27% less than monocropped yields but they were 28% higher than double cropped soybean yields (Reinbott et al. 1987).

2.5. Corn-soybean intercrops :

In North America, soybean has traditionally been intercropped with corn or grown separately and then ensiled with corn (Morrison, 1959). A five year feeding trial showed that a corn-soybean intercrop was better for raising hogs in a field than corn alone (Etheridge and Helm, 1924). Slate and Brown (1925) reported that corn-soybean silage had 134 kg more protein ha^{-1} than corn silage. Wiggans (1935) found soybean to be better in a corn intercrop than pole bean since soybean dry weight compensated for lower corn dry weight in a mixture.

Ahmed and Rao (1982), reported LERs of corn-soybean intercrops to be 1.42 to 1.64 at 14 locations in seven tropical countries. Cordero and McCollum (1979), found the average LER for corn-soybean intercrops to be 1.23 with an L_a of 0.85 for corn and an L_b of 0.38 for soybean. Putnam et al. (1985) reported that LERs increased up to 1.18 in corn-soybean intercrops as the corn population density increased. LERs were at 1.2 in the corn-soybean intercrops of Toniolo et al. (1987).

2.5.1 Selection of corn hybrids and soybean varieties for intercropping .

The most important criterion for choosing a corn hybrid or soybean cultivar in monocrops and intercrops is the maturity rating or CHUs for the growing area. If crops mature too early, advantages of the potential growth in the entire season will be lost. If the season is too short for maturity to occur the seed will probably be of poor quality. Consideration should also be given to disease resistance, especially to diseases prevalent in the area (Tanner and Hume, 1978; Upfold and Morris, 1987; Upfold and Olechowski, 1988). Hybrids selected for corn silage production should be 100 to 200 CHUs later than for grain production (Upfold and Morris, 1987). Lodging resistance is critical for soybean in intercrops because as a shaded crop it tends to grow taller to stretch toward restricted light thus resulting in plants more prone to lodge (Makena and Doto, 1980 and Chiu and Shibles, 1984).

Plant height, especially of the dominant crop, has often been deemed to influence intercrop yields. Thompson et al. (1976) achieved soybean yields 17% higher under dwarf maize than under tall maize. However, Woolley and Rodriguez, (1987), found that the tallest maize plants reduced bush bean yields less, apparently because light could more readily penetrate between the tall maize leaves on stalks with longer internodes. Donald (1963) explained that as the internodal distance increased in small-grain cereals and corn, the downward penetration of light increased asymptotically. Wahua et al. (1981) correlated increased light transmission through maize canopies with higher associated cowpea yields. Maize morphology seemed to be of more importance than maize height. The most light was transmitted by a short cultivar with erect leaves and the least by a taller cultivar with floppy leaves.

Productivity of a crop in a pure stand should be distinguished from competitive ability in association with another crop (Donald, 1963). Ranking corn hybrids by yield in a monocrop and an intercrop can be used to detect differential effects of the cropping systems. Smith and Francis (1986), noted that if the four highest yielding of twenty maize cultivars had been selected in monocrop (20% selection pressure) only one would have been included in the best four of an intercrop with bush beans and two of the best four in an intercrop with climbing beans. A fify percent selection pressure or ten selected monocrop cultivars, would have been necessary to include eight or seven of the best ten in respective intercrops. However, in the original paper (Francis et al. 1983) the cropping system by maize cultivar interaction was not significant. Davis and Garcia (1983) also monocropped and intercropped three maize cultivars with beans but again, there was not an interaction of maize genotype by cropping system.

Fifty soybean genotypes were compared in monocrops and intercrops with corn (Sharma and Mehta, 1988). There was a strong genotype x cropping system interaction for seed yield and its components which implies that selection is necessary for different varieties for each cropping system. However, separate breeding programs would not be necessary for traits such as days to flowering, plant height, 100-seed weight, oil concentration and protein concentration. In another trial, twenty soybean cultivars intercropped with each of millet, maize and sorghum had significant genotype by cropping system interactions for every soybean characteristic measured, including seed yield (Makena and Dota, 1980).

2.5.2 Corn and soybean plant spacing patterns :

The corn spacing pattern of wider intra-row spaces with three corn plants per hill allowed improved soybean yields in an intercrop with little effect to the corn (Chiu and Shibles, 1984). Widening the rows from 70 cm to 85 or 105 cm did not increase soybean production. Mohta and De (1980), found that intercropping did not significantly influence corn yields. Soybean yields were best when planted between wide corn rows of 120 cm or in alternate 60 cm rows as opposed to being planted within corn rows. Pendleton et al. (1963) planted a strip-crop of six, 60 cm corn rows alternating with six, 60 cm soybean rows and found that the 20% corn yield increase was offset by the 20% soybean yield decrease.

2.5.3 Corn and soybean plant population densities :

Putnam et al., (1985) observed a forage yield plateau at high densities of monocropped corn but there was a linear increase of intercropped forage yields with increasing densities of the corn component. Mohta and De (1980), had their best corn-soybean intercropping results when corn densities were maintained at monocrop densities. Anwarhan (1984), reported the highest corn monocrop grain yields at the most dense corn population and the highest soybean monocrop grain yields at the least dense soybean population. The best intercrop yields were with the lower population densities of each crop.

2.5.4 Nitrogen fertilizer applications to corn and soybean :

Nitrogen fertilizer applied to a corn-soybean intercrop increased corn grain yields up to 336% at 120 kg N ha^{-1} in the first year but the increase was 64% in the second year at 40 kg N ha^{-1} with no further yield response to N fertilizer (Pal et al. 1988). Unfortunately, year effects were confounded because a pure line corn variety was used in the first year and compared to a hybrid in the second year. Soybean yields were unaffected by N fertilizer and LERs followed the trend of corn yields. Cordero and McCollum (1979) noted an increase of corn intercrop yields up to application rates of 160 kg N ha^{-1}. Soybean intercrop yields were inversely related to N application rates.

Singh et al. (1986) attributed the effect of intercropping soybean with maize as being equivalent to the addition of 80 kg N ha^{-1}. Pandey and Pendleton (1986) ploughed down (42 days after planting) the two outer rows of three rows of soybean growing between wide maize rows. At 0 and 50 kg N fertilizer ha^{-1}, 28 and 25 kg N ha^{-1} respectively, were derived from the two rows of soybean ploughed down as green manure. The remaining centre soybean row was left until harvest, contributing to LERs greater than one. Nair et al. (1979) reported that in maize-soybean intercrops, intercropped maize yields alone were increased by 19.5% at 40 kg N ha^{-1} and by 27.9% at 120 kg N ha^{-1} compared to monocropped maize at respective N rates. The lower N rate in the intercrop was the most cost effective option.

Corn and soybean can compete for N when no N is applied (Allen and Obura, 1983). Nitrogen fixation in soybean may not be inhibited by medium N levels (40 to 80 kg N ha^{-1}) and may even be enhanced by better early legume growth and other synergistic effects between a moderate N level and N_2 fixation (LaFavre and Eaglesham, 1984; Eaglesham et al , 1983). The possible detrimental effects of medium N levels on N_2 fixation may be minimized in an intercrop, since soil and fertilizer N is probably used by corn more than soybean. Preferential use of N fertilizer by corn can also be achieved by placing N adjacent to corn rows only, as has been done in cereal-legume intercrops (Nambiar et al 1983 and Harris et al. 1987). At high rates of N application (> 100 kg N ha^{-1}) there may be more than enough N for the growth of both crops and possibly enough to inhibit nodulation (Bhangoo and Albriton, 1976) and thereby decrease intercropping efficiency.

2.5.5 Quality of corn-soybean silage :

Toniolo et al., (1987) reported a crude protein concentration of 10.2% in a corn-soybean intercrop, which was significantly greater than that of monocropped corn. Putnam et al., (1986) and Herbert et al., (1984) found values of 10.3% and 10.8%, respectively. Putnam et al. (1986), noted increases of 11 to 51% in crude protein concentrations of corn-soybean intercrops compared to corn monocrops. The percent protein required for balanced livestock silage feed varies: for example, 12 to 14% for growing cattle, 10 to 12% for finishing steers (Natnl. Res. Coun., 1984) and 16% for most lactating dairy cows (Miller, 1979).

The amount of crude protein harvested from each hectare may be a better indication of whether intercropping can improve silage quality. In field crops there tends to be an inverse relationship between biomass yield and crude protein concentration. Therefore, it may be more difficult to increase crude protein yield than biomass yield. In earlier experiments, intercropped corn-soybean silage had 134 kg ha^{-1} more protein than silage of monocropped corn (Slate and Brown, 1925). Herbert et al. (1984) observed significantly greater protein amounts in silage of corn-soybean intercrops than in corn silage, in two of three seasons. Putnam et al. (1986) measured as much as 1666 kg ha^{-1} of protein in silage of a corn-soybean intercrop.

Although corn yield and energy from corn may be reduced and diluted by soybean, the average 20% oil level of soybean seeds contributes considerable energy (Hume et al., 1983). In a feeding trial with sheep (Murphy et al., 1984), corn-soybean silage had higher protein, lignin and ash and lower cell wall constituents and acid-detergent fiber than corn silage, but the digestibilities of all components were the same, including digestible energy. Another intercrop of corn and soybeans had lower energy values than monocropped corn but the intercrop gave the highest yield of fat and methionine as well as of crude protein when compared to each monocrop (Beets, 1977).

2.6 Hypotheses :

The overall hypothesis of the research was that biomass and protein silage yields of intercropped corn and soybean were expected to be higher than production of the same silage material through cultivation of monocrops, on the same land area, and in a cool temperate region. Corn-soybean intercrops have been field-tested previously in the tropics or in warm temperate regions with long growing seasons (Dalal, 1977; Mohta and De, 1980; Putnam et al. 1985; Fisher et al. 1987 and Yunasa, 1989). Crookston and Hill (1979) found that corn-soybean intercrops either reduced land usage for grain yields or did not improve it beyond that achieved from monocrops. They speculated that one of the factors limiting intercropping yields in their study was the northern location at 45^{o}N, with it's short season. Ottawa is also at 45^{o}N latitude in an area of 2500 - 2600 Corn Heat Units. The short growing season is near the northern limits for economical corn and soybean production, but it was hypothesized that corn-soybean intercrops could yield higher than monocrops on the same land area. More specific hypotheses were that:

- tall corn would yield more than dwarf corn or that it would allow associated soybean to yield more than would dwarf corn,
- increasing N levels would increase biomass and protein yields in

corn monocrops and in corn-soybean intercrops,

- the cost effectiveness of corn-soybean intercrops could be higher than monocropped corn at 120 kg N ha^{-1},
- the optimum population density would be 67% corn and 67% soybean in corn-soybean intercrops,
- soybean nodulation would increase biomass yields and protein concentrations and protein yields of corn in corn-soybean intercrops,
- the optimum plant spacing patterns for corn-soybean intercrops were alternate rows of corn and soybean,
- grain corn and soybean seed yields could be as high in stripcrops as in intercrops,
- the percent infestation of European corn borer would be lower in intercropped corn than in mononcropped corn,
- dwarf and tall corn would be infested similarly by European corn borer,
- increasing N fertilizer levels would increase European corn borer infestation,
- corn yields would decrease as European corn borer infestation increased,
- nitrogen would be transferred from nodulating soybean to corn and to nonnodulating soybean as detected by the ^{15}N dilution method,
- N transfer would be more clearly detected by the ^{15}N dilution method on N-depleted soil than on non-N-depleted soil,
- N transfer would be observed by applying ^{15}N enriched N directly to petioles or to roots of nodulating soybean in field trials,
- N transfer could be seen in a greenhouse, from nodulating soybean to corn or to nonnodulating soybean, by applying enriched N to secondary roots of nodulating soybean in a split-root system.

2.7 Objectives :

The objectives were:

- to compare yields of corn and soybean in monocrops and intercrops and to evaluate intercropping land use efficiency with LERs,

- to compare protein yields and concentrations of corn and soybean and corn-soybean silage,
- to compare the suitability of dwarf corn and tall corn for intercropping with soybean,
- to assess the effect of three N levels on yields and protein concentrations and yields in corn-soybean intercrops,
- to evaluate the cost effectiveness of corn-soybean intercrops as compared to monocropped corn under normal agronomic conditions,
- to determine the optimum population densities of corn and soybean in corn-soybean intercrops,
- to assess the effects of soybean nodulation on yields and protein concentrations and protein yields in corn-soybean intercrops,
- to determine the optimum plant spacing patterns for corn and soybean in corn-soybean intercrops,
- to compare grain corn yields in intercrops and stripcrops,
- to determine the effects of intercropping dwarf and tall corn with soybean on European corn borer infestation,
- to determine the effects of three N fertilizer levels on European corn borer infestation,
- to assess corn and corn-soybean silage yields in treatments with known levels of infestation by European corn borer,
- to test nitrogen transfer from nodulating soybean to corn and to nonnodulating soybean with the ^{15}N dilution method in field experiments in three relatively short and cool growing seasons,
- to compare N transfer on a field site with soil depleted and not depleted of soil N,
- to assess N transfer by applying enriched ^{15}N directly to nodulating soybean and to compare the methods of applying ^{15}N to petioles or to roots of nodulating soybean in field trials,
- to assess N transfer from nodulating soybean to nonnodulating soybean, in a greenhouse, by applying enriched ^{15}N to secondary roots of a split-root system.

Several objectives are addressed in each of the following four sections of the thesis. All objectives are discussed in the general discussion section.

Preface to Section 3

Section 3 is part of the manuscript by Martin et al. (1990a) submitted to the journal, Field Crops Research. The format has been changed to conform as much as possible to a consistent format within this thesis. All literature cited in this section is listed in the reference section at the end of the thesis. Each table is presented on the page following the first referral to it. The abstract for section 3 is longer than many but was written according to the guidelines of Field Crops Research.

The basic agronomic feasibility of corn-soybean intercropping at 45° N is addressed in section 3 to set the stage for more specific assessments in following sections. The main 2 x 2 x 3 factorials of two corn hybrids, two cropping systems and three N levels in 1985 and 1986 are presented. Several other treatments of the overall incomplete factorials of 1985 and 1986 are also included in this core section of yield, protein and cost effectiveness data.

Section 3

INTERCROPPING CORN AND SOYBEAN FOR HIGH-PROTEIN SILAGE IN A COOL TEMPERATE REGION: YIELD, PROTEIN AND ECONOMIC EFFECTS

3.0. Abstract :

Corn (*Zea mays* L.) and soybean (*Glycine max* [L.] Merr.) were intercropped for silage in 1985 and 1986 at the Central Experimental Farm, Ottawa, Canada to evaluate silage yield, protein and economic effects. In both years, a complete 2 x 2 x 3 factorial was analysed for two corn hybrids (dwarf and tall), two corn cropping systems (monocropped and intercropped), and three N fertilizer levels (0, 60 and 120 kg N ha^{-1}). In addition to the complete factorial treatments, monocropped soybeans with 0 kg N ha^{-1} and an intercrop treatment of dwarf and tall corn at 120 kg N ha^{-1} were grown. In 1986, four different population density combinations of the intercropped tall corn and soybean, at 60 kg N ha^{-1}, were also compared.

Total yields averaged over corn hybrids and cropping systems had a quadratic response, increasing from 0 to 60 kg N ha^{-1} and then decreasing slightly between 60 and 120 kg N ha^{-1}, in both years Monocrops of corn yielded significantly more in both years than intercrops except tall corn intercrops in 1986 grown at monocropped corn population densities. Both corn and soybean of the dwarf corn intercrops in the dry year of 1985 had a consistent trend of lower dry matter and protein yields than in tall corn intercrops at the same levels of N. These differences did not consistently favour either corn hybrid in 1986.

The concentration of crude protein was significantly higher in intercropped than monocropped silage in both years. In 1986, this was also true for the protein yield ha^{-1}. Increasing N applications resulted in higher total silage protein concentrations in both years. The total silage protein concentration was, on average, 1.53 and 2.15 percentage points higher in intercrops than in the corresponding monocropped corn hybrid at the same level of N in 1985 and 1986, respectively. The total silage protein concentration in both years and the protein yield in 1986 were higher for tall corn than dwarf corn.

All treatments at 0 kg N ha^{-1}, the dwarf corn intercrops in 1985 and monocropped dwarf corn at 120 kg N ha^{-1} in both years, were less cost effective than the standard, monocropped tall corn at 120 kg N ha^{-1}. In 1985, the tall corn intercrop at 60 kg N ha^{-1} had a \$135 ha^{-1} cost effective advantage over the standard treatment. In 1986, this intercrop had a \$132 ha^{-1} advantage which was improved to \$261 ha^{-1} when the corn population was maintained at monocrop levels and the population of soybeans was reduced by 50%. Land equivalent ratios (LERs) based on dry matter weights ranged from 0.97 to 1.11 in dwarf corn intercrops and from 1.16 to 1.23 in tall corn intercrops in 1985. The LER range in 1986 was from 1.11 to 1.12 in dwarf corn intercrops and from 1.04 to 1.23 in tall corn intercrops.

3.1. Introduction :

Corn (Zea mays L.) and soybean (Glycine max [L.] Merr.) have been intercropped successfully in North America since the early part of this century (Etheridge and Helm, 1924; Slate and Brown, 1925). A five year feeding trial of foraging hogs in a field showed that a combination of corn and soybean was better than corn alone (Etheridge and Helm, 1924). Frequently, soybean was intercropped with corn or grown separately and then ensiled with corn. When used as a hay crop, soybean was found to be as rich as alfalfa in protein and worth 80 - 90% of the feeding value of alfalfa hay (Morrison, 1959). In Ontario, soybean was first introduced as a hay crop in 1893 but since World War II soybean has mostly been grown for soy oil extraction and the soy meal by-product (Upfold and Olechowski, 1988). Recently, corn and soybean intercropping has received more attention, based on advantages it may have in modern agriculture. For example, Toniolo et al. (1987), reported that intercrops of corn and soybean for silage had higher protein contents than sole corn and dry matter land equivalent ratios (LERs) of up to 1.2. Putnam et al. (1986), noted increases of 11 - 51% in crude protein concentrations of corn-soybean intercrops compared to corn monocrops.

Yield and quality advantages due to intercropping corn and soybean have also been documented by other researchers (Beets, 1977; Ahmed and Rao, 1982; Allen and Obura, 1983; Herbert et al. 1984 and Putnam et al. 1985). However, most of these studies have been in tropical, sub-tropical or warm temperate regions with long growing seasons. Economic assessments have not generally been included.

In this paper we evaluate yield and quality (concentration and yields of protein ha^{-1}) of corn monocrops and intercrops of corn and soybean for silage, in a cool temperate region. Ottawa is at 45^{o}N latitude in an area of 2500 - 2600 Corn Heat Units (Brown, 1981). The short growing season is near the northern limits for economical corn and soybean production. A newly introduced dwarf corn hybrid, developed in part for cultivation in northern areas, was compared to a tall corn hybrid, in monocropping, intercropping with soybean and in a mixture of dwarf and tall corn. An economic analysis is included to measure 15 monocrop and intercrop treatments against the standard production practice of monocropping tall corn with a high rate of N application.

3.2. Materials and Methods :

Two similar experiments were conducted in 1985 and 1986, at the Central Experimental Farm of Agriculture Canada in Ottawa, Canada, (45^o, 27' N latitude and 75^o, 42' W longtitude) on a Granby sandy loam (Typic Haplaquoll). The 1986 site was about 1 km from the 1985 site. Each site was fall-plowed and cultivated twice the following spring prior to seeding. Weeds were controlled both years a by pre-emergent application of metolachor and linuron at 2.2 and 1.1 kg a.i. ha^{-1}, respectively. Weeds were also removed by hand, when necessary.

The summer of 1985 was relatively dry. Total rainfall in May, June, July, August and September was 68.1, 94.8, 67.2, 71.1 and 46.2 mm, respectively, compared with 164.3, 107.0, 144.4, 99.0 and 167.6 mm of rainfall in the same months of 1986 (Environment Canada, 1985 and 1986).

In both years the corn hybrids, Coop S259 (tall) and PAG 391134 (dwarf), and 'Maple Arrow' soybeans were planted simultaneously in mid-May and harvested, as whole plants for silage in late September. A commercial granular inoculant of Bradyrhizobium japonicum, (Nitragin Co.) was applied into the drill row, with the soybean seed, at planting. Ammonium nitrate fertilizer was applied three weeks after planting, by forming a shallow trench with a hoe, 10 to 15 cm from both monocropped and intercropped corn rows, sprinkling measured volumes evenly into each trench and covering immediately with three to five cm of soil. There were two trenches per row, one on each side, for applications of 120 kg N ha^{-1}. N fertilizer was applied only to corn rows to minimize inhibitory effects on N_2 fixation by soybeans. Soil tests of P and K indicated sufficient levels of each, in both years, and therefore P and K were not applied.

In this study, a complete 2 x 2 x 3 factorial was analysed for two corn hybrids (dwarf and tall), two corn cropping systems (monocropped and intercropped), and three nitrogen fertilizer levels (0, 60 and 120 kg N ha^{-1}). In addition, treatments of monocropped soybean at 0 kg N ha^{-1} and a mixture of dwarf and tall corn at 120 kg N ha^{-1} were assessed. The treatments of this study formed part of a larger intercropping experiment, designed as an incomplete factorial in a randomized complete block design with four replications.

In 1986, four population densities of the intercrop of tall corn and soybean at 60 kg N ha^{-1} were also compared. The population density levels were percentages of respective monocrops in ratios of 67% corn : 67% soybean (P1), 50% corn : 50% soybean (P2), 100% corn : 50% soybean (P3) and 100% corn : 100% soybean (P4). P1, P3 and P4 were additive populations and P2 was a replacement population. In both years, monocropped plant populations were 60,000 plants ha^{-1} of tall corn, 150,000 plants ha^{-1} of dwarf corn and 500,000 plants ha^{-1} of soybeans To achieve adequate yields with small cobs and short statured plants, dwarf corn must be planted at a population 2.5 times that of tall corn For the 2 x 2 x 3 complete factorial the additive population density, P1, was used in the intercrop treatments. Each component crop of the dwarf-tall corn mixture was also planted at 67% of it's monocrop population density.

Each plot consisted of 12 rows, 40 cm apart and 6.5 m in length. The spacing pattern of monocrops was according to normal agronomic recommendations. Dwarf corn and soybean monocrops were planted in twelve 40 cm rows but tall corn monocrops consisted of six 80 cm rows. Tall corn intercrops were planted with corn and soybean plants in alternate 40 cm rows, whereas the dwarf-tall corn mixture and dwarf corn intercrops had both component crops in the same 40 cm row. N fertilizer was therefore placed closer to soybean in the latter spacing pattern than in other intercrops. This arrangement was selected because excessive intraspecific competition was expected in the high population of dwarf corn when grown in rows 80 cm apart. The inter-row and intra-row intercrop spacing patterns were tested with each corn hybrid in 1986. The check factorial showed that yields of corn, soybean and the two crops combined were not different between the spacing patterns or between the corn hybrids. Nevertheless, because of possible confounding effects of corn hybrid, spacing pattern and N placement near soybean, comparisons between dwarf and tall corn should be interpreted with caution.

Wet weight yields were determined from the centre 2.5 m of the middle four rows in each plot. A representative subsample of 3 - 4 corn plants and 10 - 20 soybean plants from each plot was weighed in the field at harvest, oven-dried at 80^{o} C for at least 72 hrs., and weighed again to determine the moisture content. The whole plants were chopped with a corn silage chopper and then ground in a Wiley mill (20 mesh sieve). The concentration of total reduced nitrogen was determined on ground tissue by Kjeldahl analysis (Tecator, Kjeltec 1030 Auto Analyzer). Crude protein was calculated as 6.25 times percent N

Biomass yields and crude protein concentrations and yields were subject to analysis of variance (SAS Institute Inc., 1982) at the 5% level of significance. The main effect of each factor and all possible interactions were also considered. When significant differences were found, a protected LSD test was applied for comparisons between means (Steel and Torrie, 1980).

The cost effectiveness in 1987 Canadian $ of each treatment was determined as the difference between the calculated value of the silage and the variable costs per hectare. Each treatment was then compared to the cost effectiveness of the standard agronomic practice of monocropping tall corn at 120 kg N ha^{-1}. Fixed costs, defined here as those which were the same for every treatment, were not included in the calculations.

Harvested corn plants, adjusted to 70% moisture levels, were valued at \$25.00 t^{-1}. Soybean was evaluated at \$0.80 kg^{-1} of crude protein in the harvested shoot (dry wt.). This value was derived from the price of \$384 t^{-1} for 48% protein soymeal. Depending on the overall diet, ruminants may obtain about equal to somewhat less protein value from one kg of nitrogen in ensiled soybean plants compared to one kg of nitrogen in soymeal (D. Viera, Agriculture Canada, pers. comm.). McCormick et al. (1983), found that the average daily gain of beef calves was similar with either whole soybean seeds or soymeal as a protein supplement. Whole soybean seeds contain at least 90% of the nitrogen in a soybean plant (Smith et al. 1988). The carbohydrate value of the 20% oil content in soybean seeds (Hume et al. 1983) was not credited in our study and probably more than compensates for possible lower protein availability of soybean silage to cattle.

The variable costs included nitrogen fertilizer and seeds. N was assessed at \$0.60 kg^{-1} assuming urea fertilizer to be worth \$276 t^{-1}. Seed costs were \$80 for 80,000 seeds of tall corn, \$70 for 80,000 seeds of dwarf corn, and \$9 for 150,000 soybean seeds, including inoculant.

LER values were calculated as LER $= L_a + L_b$ where L_a is the fraction of the yield of intercropped corn relative to the yield of monocropped corn and L_b is the fraction of intercropped soybeans relative to the yield of monocropped soybeans (Mead, 1986). Since the level of management should be as similar as possible for each cropping system, LERs were calculated with the same levels of N for intercropped and monocropped corn. Soybeans were only monocropped at 0 kg N ha^{-1} because yields of this legume, when well-inoculated, generally do not respond economically to applied levels of N in soils which are not deficient in N (Dadson and Acquaah, 1984 and Eaglesham et al. 1983). Therefore, all LER values were derived from monocropped soybeans at 0 kg N ha^{-1} in the L_b fraction.

3.3. Results :

Soybean biomass yields were 21% to 28% of the total intercrop yield with both dwarf and tall corn at 0 kg N ha^{-1} in both years (Table 3.1) At the 60 and 120 kg N levels soybean yields were 14% to 19% of the intercrop yields. Clearly, corn was the dominant crop. In all but one intercrop, the proportion of soybeans was 1% to 5% higher in 1986 than in the dry year of 1985. The exception was the tall corn intercrop at

Table 3.1. Dry weight yields in 1985 and 1986.

Treatment		Yield (kg ha^{-1})					
Crop	N	1985			1986		
a b		Corn	Soy	Total	Corn	Soy	Total
Dwarf	0	9127	--	9127	10995	--	10995
Dwarf	60	11450	--	11450	14684	--	14684
Dwarf	120	10762	--	10762	14166	--	14166
Dwarf-Soy	0	5506	1502	7008	7319	2874	10193
Dwarf-Soy	60	7272	1461	8733	10775	2496	13271
Dwarf-Soy	120	8254	1377	9631	10896	2246	13142
Tall	0	7591	--	7591	10423	--	10423
Tall	60	10319	--	10319	14408	--	14408
Tall	120	10398	--	10398	13946	--	13946
Tall-Soy	0	5627	1700	7327	8691	2483	11174
Tall-Soy	60	8868	1485	10353	10760	2453	13213
Tall-Soy	120	8364	1594	9958	10605	2392	12997
Soy	0	--	4045	4045	--	6447	6447
Dwarf-Tall	120	8026	4438[1]	12464	9095	6603[1]	15698
LSD - All Trts.		2421[2]	435[2]	2383[3]	1603[2]	814[2]	1611[3]
LSD - Monocrops		NS	--	--	2205	--	--
LSD - Intercrops		2067	NS	1963	1110	NS	1144
LSD - 120N Trts.[4]		--	--	NS	--	--	1558

N = kg N ha^{-1}; LSD = protected least significant difference at P = 0.05; NS = not significant; [1] Soy value of this column replaced by tall corn value; [2] Excluding dwarf-tall; [3] Excluding dwarf-tall and monocropped soybean; [4] Excluding monocrops.

0 kg N ha^{-1} in which soybean was 23% of the yield in 1985 and 22% in 1986. Soybean yields did not differ significantly between intercrops but tended to decline from 0 to 60 to 120 kg N ha^{-1}.

In 1986, at 120 kg N ha^{-1}, the total yield was higher for the mixture of tall and dwarf corn than for either corn-soybean intercrop (Table 3.1). There was a similar, although not significant, trend in 1985.

In both years, the total yields of corn plus soybean were increased by the application of 60 kg N ha^{-1} as a nitrogen main effect. There was no further increase when 120 kg N ha^{-1} was applied (Table 3.2). Corn yields responded similarly (Table 3.1). Although the decrease at 120 kg N ha^{-1} was not significant in the ANOVA, regression analysis showed a significant quadratic total yield response to N in the dry year of 1985 (means, but not regression analysis, shown in Table 3.2). The quadratic total yield response was also significant in the wet year of 1986. Silage yield of monocropped corn exceeded that of the total intercrop yield in each year. No differences were observed between tall and dwarf corn hybrids. There were no significant interactions of the three factors (corn hybrid, cropping system, and N fertilizer level) for total silage yield in either year.

The total yield levels at 120 kg N ha^{-1} in 1985 under reduced moisture levels, were about equal to those at 0 kg N ha^{-1} in 1986. In 1985, the dwarf corn intercrops, sown at a high population density, showed the most wilting. Both component crops in the dwarf corn intercrops had a consistent trend of lower biomass and protein yields compared to tall corn intercrops at the same levels of N (Tables 3.1 and 3.3). In 1986, biomass and protein yields within dwarf corn

Table 3.2. Nitrogen, corn hybrid and cropping system main effects of biomass dry weight yields, protein yields and concentrations of total corn and soybean silage in 1985 and 1986.

Main Effect	Biomass		Protein			
	Yield (kg ha^{-1})		Yield (kg ha^{-1})		Concentration (%)	
N	1985	1986	1985	1986	1985	1986
0	7764	10696	557	838	7.29	7.83
60	10214	13894	810	1183	8.02	8.58
120	10187	13563	893	1271	8.80	9.42
LSD	1191	805	91	Int	0.55	Int
Corn Hybrid						
Dwarf	9452	12742	723	1051	7.73	8.27
Tall	9324	12693	783	1144	8.34	8.95
LSD	NS	NS	NS	62	0.45	Int
Cropping System						
Monocrop	9941	13104	726	1000	7.27	7.54
Intercrop	8835	12332	780	1195	8.80	9.68
LSD	973	658	NS	Int	0.45	Int

N = kg N ha^{-1}; LSD = protected least significant difference at $P = 0.05$; NS = not significant; Int = significant interaction of main effects

Table 3.3. Protein yields in 1985 and 1986.

Treatment		Protein Yield (kg ha^{-1})					
Crop	N	1985			1986		
a	b	Corn	Soy	Total	Corn	Soy	Total
Dwarf	0	573	--	573	670	--	670
Dwarf	60	743	--	743	1070	--	1070
Dwarf	120	859	--	859	1106	--	1106
Dwarf-Soy	0	307	234	541	494	496	990
Dwarf-Soy	60	513	234	747	785	406	1191
Dwarf-Soy	120	655	222	877	810	466	1276
Tall	0	489	--	489	699	--	699
Tall	60	844	--	844	1149	--	1149
Tall	120	850	--	850	1304	--	1304
Tall-Soy	0	313	311	624	606	386	992
Tall-Soy	60	621	286	907	869	453	1322
Tall-Soy	120	717	269	986	954	445	1399
Soy	0	--	612	612	--	1187	1187
LSD - Monocrops		211	--	--	177	--	--
LSD - Intercrops		196	NS	177	115	NS	154
LSD - All Trts.		189	99	179	140	162	163
LSD - All Trts.[1]		--	--	183	--	--	153

N = kg N ha^{-1}; LSD = protected least significant difference at P = 0.05; NS = not significant; [1] Excluding monocropped soybean.

intercrops were sometimes higher than corresponding responses within tall corn intercrops.

The soybean monocrop protein yield ha^{-1}, in 1986, was significantly greater than the total protein yield of each of the corn monocrops and intercrops at 0 kg N ha^{-1} (Table 3.3). In 1985, about half the protein yield was found in monocropped soybeans (compared to 1986) and it was less than in monocropped dwarf corn at 120 kg N ha^{-1} and tall corn at 60 and 120 kg N ha^{-1}. Soybean protein yields were not significantly different between intercropped treatments, in either year. Soybean contributed large proportions of protein to the intercrops; 39% to 50% at 0 kg N ha^{-1} and 25% to 37% at 60 and 120 kg N ha^{-1} over both years.

The N main effects on total silage protein yields showed an increase from 0 kg N ha^{-1} to 60 kg N ha^{-1} but no further significant increase at 120 kg N ha^{-1} in 1985 (Table 3.2). The protein yields in monocropped corn followed a similar pattern in both years (Table 3.3). In 1985, neither corn hybrid nor cropping system affected total protein yields and there were no interactions between N level, corn hybrid or cropping system (Table 3.2). In 1986, tall corn had higher total protein yields ha^{-1} than dwarf corn. The N x cropping system interaction was significant ($p = 0.0485$) and therefore simple effects rather than main effects were compared statistically. The trends within the N and cropping system factors were the same as in 1985. Intercrop total protein yields were higher than those of monocrops contrasted at each level of N, averaged over the corn hybrids (contrasts not shown in tables).

The total silage crude protein concentrations of intercropped tall corn were 9.95% at 120 kg N ha^{-1} in 1985 and 10.04% at 60 kg N ha^{-1} and

10.76% at 120 kg N ha^{-1} in 1986 (Table 3.4). The silage protein concentration was, on average, 1.53 and 2.15 percentage points higher in intercrops than in the corresponding monocropped corn hybrid at the same level of N in 1985 and 1986 respectively. These protein percentage point increases at 0 kg N ha^{-1} were 1.58 and 2.22 in 1985 and 2.27 and 3.62 in 1986. At 60 and 120 kg N ha^{-1} these increases ranged from 0.44 to 2.08 over both years. Monocropped soybean protein concentrations were not different from intercropped soybean values in 1985 but in 1986, monocropped soybean was less than soybean in the dwarf corn intercrop at 120 kg N ha^{-1} and higher than soybean in the intercrops of dwarf corn at 60 kg N ha^{-1} and tall corn at 0 kg N ha^{-1}.

There were no interactions for the main effects of total silage protein concentration in 1985; however, in 1986 interactions occurred between N and cropping system ($p < 0.006$) and N and corn hybrid ($p < 0.002$) (Table 3.2). The lower value of the dwarf corn intercrop at 60 kg N ha^{-1} than at 0 kg N ha^{-1} was in contrast to the trends of other treatments (Table 3.4). In 1985, crude protein concentration was higher in intercropped silage than in monocropped corn silage and it was greater in tall corn silage than in dwarf corn silage (Table 3.2). It increased significantly from 0 kg N ha^{-1} to 60 kg N ha^{-1} and again between 60 and 120 kg N ha^{-1}. In 1986, the same trends were clear, but because of the aforementioned interactions, simple effects rather than main effects were compared statistically. All intercrop values were higher than any corn monocrop value, except for tall monocropped corn at 120 kg N ha^{-1}, and intercropping was significantly higher than monocropping when cropping system levels were contrasted at each level of N, averaged over the corn hybrids (contrasts not shown in tables).

Table 3.4. Protein concentrations in 1985 and 1986.

Treatment		Protein Concentration (%)					
Crop	N	1985			1986		
a b		Corn	Soy	Total	Corn	Soy	Total
Dwarf	0	6.34	--	6.34	6.11	--	6.11
Dwarf	60	6.48	--	6.48	7.29	--	7.29
Dwarf	120	8.00	--	8.00	7.81	--	7.81
Dwarf-Soy	0	5.62	15.59	7.92	6.77	17.28	9.73
Dwarf-Soy	60	7.06	16.14	8.56	7.28	16.18	8.98
Dwarf-Soy	120	7.84	16.33	9.08	7.45	20.73	9.72
Tall	0	6.33	--	6.33	6.61	--	6.61
Tall	60	8.31	--	8.31	8.01	--	8.01
Tall	120	8.16	--	8.16	9.38	--	9.38
Tall-Soy	0	5.56	18.39	8.55	6.95	15.43	8.88
Tall-Soy	60	6.94	19.33	8.75	8.10	18.58	10.04
Tall-Soy	120	8.58	16.76	9.95	8.99	18.44	10.76
Soy	0	--	15.01	15.01	--	18.43	18.43
LSD - Monocrops		1.11	--	--	0.77	--	--
LSD - Intercrops		1.12	NS	NS	0.79	2.20	1.00
LSD - All Trts.		1.03	NS	1.09[1]	0.73	2.15	0.82[1]

N = kg N ha^{-1}; LSD = protected least significant difference at P = 0.05; NS = not significant; [1] Excluding monocropped soybean.

The total yields of intercrops with corn populations maintained at monocrop densities, P3 and P4, were both significantly greater than each of P1 and P2 (Table 3.5). The yield of the corn component of these intercrops followed the same trend. The monocropped corn (P0) yield was somewhat (not significantly) less than the total yield of P3 and P4 unlike the significantly higher monocrop responses in the 2 x 2 x 3 factorial (Table 3.2). The protein yield of P0 was higher than corn of all intercrops except P3 and lower than the total silage of all intercrops except P2 (Table 3.5). Despite varying degrees of competition, soybean biomass and protein yields were not significantly different between treatments.

It was clear that at 0 kg N ha^{-1}, the biomass yields and protein yields and concentrations of corn were lower in both monocrop and intercrop treatments compared to treatments with applied N. In accordance with these observations, the cost effectiveness of treatments without applied N were all less than the standard, monocropped tall corn at 120 kg N ha^{-1} (Table 3.6). In 1985, the tall corn intercrop at 60 kg N ha^{-1} had the highest cost effective advantage of \$135 ha^{-1}. This was considerably larger than the \$44 ha^{-1} advantage of the tall corn intercrop at 120 kg N ha^{-1}. The corn mixture of two hybrids together, at 120 kg N ha^{-1}, was \$104 ha^{-1} more cost effective than the standard tall corn at 120 kg N ha^{-1}. In 1986, the most successful treatment of 1985 (the tall corn intercrop at 60 kg N ha^{-1}), was tested at four population densities in an attempt to further improve this intercrop. At the P1 population density the \$132 ha^{-1} cost effective advantage of this treatment was about the same as in 1985 but the P3 and P4 variations of this treatment were even more

Table 3.5. Dry weight biomass and protein yields of population treatments in 1986.

Treatment			Biomass Yield			Protein Yield		
Crop	N	Pop'n	(kg ha^{-1})					
a b			Corn	Soy	Total	Corn	Soy	Total
Tall	60	P0	14408	--	14408	1149	--	1149
Tall-Soy	60	P1	10760	2453	13213	869	453	1322
Tall-Soy	60	P2	10093	2207	12300	814	402	1216
Tall-Soy	60	P3	13368	1818	15186	1016	368	1384
Tall-Soy	60	P4	12283	2408	14691	968	439	1407
LSD - Intercrops			1607	NS	1407	NS	NS	NS
LSD - All trts.			1482	--	1329	157	--	168

N = kg N ha^{-1}; P0 = 100% monocrop; P1 = 67% a, 67% b; P2 = 50% a, 50% b; P3 = 100% a, 50% b; P4 = 100% a, 100% b; LSD = protected least significant difference at $P = 0.05$; NS = not significant.

Table 3.6. Cost effectiveness of treatments compared to the standard monocropped tall corn at 120 kg N ha^{-1} and LERs.

Treatment			Difference from Standard ($ ha^{-1})		LER	
Crop a b	N	Pop'n	1985	1986	1985	1986
Dwarf	0	P0	- 105	- 245	--	--
Dwarf	60	P0	+ 52	+ 27	--	--
Dwarf	120	P0	- 41	- 52	--	--
Dwarf-Soy	0	P1	- 198	- 132	0.97	1.11
Dwarf-Soy	60	P1	- 88	+ 47	1.00	1.12
Dwarf-Soy	120	P1	- 51	+ 69	1.11	1.12
Tall	0	P0	- 162	- 221	--	--
Tall	60	P0	+ 29	+ 75	--	--
Tall	120	P0	0	0	--	--
Tall-Soy	0	P1	- 79	- 59	1.16	1.22
Tall-Soy	60	P1	+ 135	+ 132	1.23	1.13
Tall-Soy	60	P2	--	+ 51	--	1.04
Tall-Soy	60	P3	--	+ 261	--	1.21
Tall-Soy	60	P4	--	+ 217	--	1.23
Tall-Soy	120	P1	+ 44	+ 76	1.20	1.13
Soy	0	P0	- 277	- 196	--	--
Dwarf-Tall	120	P1	+ 104	+ 78	1.17	1.12

N - kg N ha^{-1}; P0 - 100% monocrop; P1 - 67% a, 67% b; P2 - 50% a, 50% b; P3 - 100% a, 50% b; P4 - 100% a, 100% b.

advantageous, at \$261 ha^{-1} and \$217 ha^{-1} respectively. The other treatments in 1986 had cost effective advantages which were less than \$80 ha^{-1}.

LERs ranged from 0.97 to 1.11 in dwarf corn intercrops and from 1.16 to 1.23 in tall corn intercrops in 1985 (Table 3.6). The tall corn intercrop at 60 kg N ha^{-1} had the highest LER of 1.23. In 1986, LERs of dwarf corn intercrops were 1.11 or 1.12 but LERs ranged from 1 04 to 1.23 in tall corn intercrops. The LER of the tall corn intercrop at 60 kg N ha^{-1} at P1 was 1.13 and at P2 was 1.04, but at P3 and P4 the LERs were 1.21 and 1.23 respectively. The mixture of tall and dwarf corn had an LER of 1.17 in 1985 and 1.12 in 1986.

3.4. Discussion :

The yield depression of dwarf corn intercrops under moisture stress in 1985 may have been partly due to the dense population of these intercrops. Competition in dwarf corn intercrops may also have been intense because shorter corn appears to intercept more light with leaves which are nearer the soybean understory than those of tall corn (Woolley and Rodriquez, 1987). Higher populations of tall corn in intercrops in 1986 resulted in more productivity, higher LERs and economic advantages up to \$261 ha^{-1}. Putnam et al. (1985) also increased corn densities and observed a yield plateau at high densities of monocropped corn but a linear increase of corn yields in corn-soybean intercrops.

Allen and Obura (1983), also noted lower yields in a dry season and found that corn-soybean intercrops responded more to irrigation than monocropped corn. However, they did not apply N to intercrops as they did to monocropped corn and this limitation may have been confounded with that of low moisture by exacerbating the overall stress to the intercrop. In our study, where irrigation was not a factor, the intercrop and monocrop of tall corn both responded to 60 kg N ha^{-1} in the dry year of 1985.

It was apparent that 60 kg N ha^{-1} was the optimum rate of N application in both years. Cordero and McCollum (1979) observed corn yield increases up to applications of 180 kg N ha^{-1} in corn-soybean intercrops and corn monocrops. The failure in this study of monocropped corn or total corn and soybean yields to increase from 60 to 120 kg N ha^{-1} may have been due, in part, to significantly higher infestations of European corn borer at 120 kg N ha^{-1} (Martin et al. 1989). Alternatively, nitrogen may not have been a limiting factor beyond applications of 60 kg N ha^{-1} on the soils of our study sites. It may also be that higher corn population densities would respond more to higher rates of N. For example, the mixture of dwarf and tall corn at 120 kg N ha^{-1} was as much a treatment of increased population density as it was a treatment of intercropping since both crops were of the same species. However, the higher total yield of this mixture was not significantly greater than the lower density corn monocrops at 60 or 120 kg N ha^{-1} in either year (LSD of this comparison not shown in Table 3.1).

The quality (crude protein concentration) of silage from corn-soybean intercrops was higher than silage from monocrops of corn (Table 3.4). Toniolo et al. (1987) also reported a crude protein concentration of 10.2% in a corn-soybean intercrop, which was significantly higher than monocropped corn. Putnam et al. (1986) and

Herbert et al. (1984) found values of 10.3% and 10.8%, respectively The value of 10.76% crude protein in silage of tall corn and soybean at 120 kg N ha^{-1} in the work represented here, could substantially decrease requirements for protein supplements.

The crude protein yield harvested from each hectare may be a better indication of whether intercropping can improve silage value. In field crops there tends to be an inverse relationship between biomass yield and the concentration of crude protein. Therefore it can be more difficult to increase crude protein yield than biomass yield. In 1986, more protein ha^{-1} was harvested from intercrops than monocropped corn at each level of N fertilizer. The trend was also better for intercrops in 1985 (Tables 3.2 and 3.3). Slate and Brown (1925) found that intercropped corn-soybean silage had 134 kg ha^{-1} more protein than silage of monocropped corn. Herbert et al. (1984) observed a significant increase of crude protein amounts in intercrops in two of three seasons. Putnam et al. (1986) recorded as much as 1666 kg ha^{-1} of crude protein in a corn-soybean intercrop with 10.2% crude protein Their concern about corn harvesters which fail to harvest all of the soybeans is justified, but the problem may be allieviated with new harvesters which have knives or discs underneath the corn head to cut plants closer to the ground.

Proteins of corn and soybean have complementary amino acid profiles Methionine and cystine are at adequate levels in corn but deficient in soybean and lysine, commonly deficient in corn, is at high levels in soybean (Orthoefer, 1978). In a feeding trial with sheep (Murphy et al. 1984), corn-soybean silage had higher protein, lignin and ash, and lower cell wall constituents and acid-detergent fiber than corn silage, but the digestibilities of all components including energy were the same. An intercrop of corn and soybean for grain production had lower energy values than monocropped corn but the intercrop gave the higher yield of total fat (ether extract) and methionine, as well as of crude protein when compared to each monocrop (Beets, 1977).

Nitrogen fixation of soybean at 0 kg N ha^{-1} did not provide sufficient N to produce yields and protein contents equal to that of the intercrops at 60 and 120 kg N ha^{-1}. Soybean, a very competitive legume for the uptake of soil N under N limiting conditions (Johnson et al. 1975) probably competed for N in the intercrop when no N was applied. This was also reported by Allen and Obura (1983). Although nitrogen fixation was not directly measured here, it did not seem to be inhibited by 60 kg N ha^{-1}. Nodule weights and numbers of intercropped soybeans were not significantly decreased by 60 kg N ha^{-1} in either year (unpublished data). Other research (Dean and Clark, 1980) has shown decreased nodulation and N_2 fixation of soybeans by 20 kg N ha^{-1}. In our study, 60 kg N ha^{-1} may have been used quickly by corn in the intercrop and "mopped up" before it could adversely affect soybean. The closely associated corn and soybean roots may also have resulted in N transfer from soybean to corn. Elmore and Jacobs (1986) reported N transfer from soybean to sorghum under similar conditions. At 120 kg N ha^{-1} there was more than enough N for the growth of both crops and probably enough to inhibit nodulation and N_2 fixation (Smith and Hume, 1985; Bhangoo and Albriton, 1976) and thereby decrease intercropping efficiency.

Intercropping was not beneficial if total yields are used as the basis of comparison. Total intercrop yields (except P3 and P4, Table 3.5) were lower than those of monocropped corn (Table 3.1). The dominant crop of an intercrop usually yields higher without competition from an associated crop and it may produce more as a monocrop than the total intercrop yield (Gliessman, 1986). LERs account for potential yield differences of component crops in an intercrop by comparing each crop to itself and then summing the ratios. The LER of 1.23 showed that 23% more land was required in monocropping both corn and soybean to achieve the same yield as an corn-soybean intercrop.

The use of LERs is justified here because dairy farmers must supplement corn silage with protein. As noted previously, it was common practice to feed soybeans as a forage before soy oil extraction became a major industry and the by-product, soymeal, became widely available as a feed. Today soybean is not grown as a monocrop for silage but is still grown on some farms to be harvested as whole soybeans for the high protein content. This is especially true in western Quebec and eastern Ontario where the soybean micronization process has resulted in a large increase of heat-treated whole soybeans fed to cattle as a protein supplement. Carbohydrate in whole soybeans also has value in livestock rations. Harvesting intercropped soybeans for silage creates an opportunity to grow a corn-soybean intercrop which probably could not be easily harvested for the grain component alone. It is not uncommon for a crop such as soybean silage to be more useful as an intercrop than as a monocrop. In many areas of Latin America, climbing beans are not grown as monocrops because of the inconvenience of erecting trellises but corn-bean intercrops have been evaluated for land use efficiency with reference to corn and bean monocrops (Francis, 1978).

The high LER of 1.22 for the tall corn intercrop at 0 kg N ha^{-1}

(Table 3.6) could lead to conclusions about restricting intercropping to systems with no inputs. However it must be pointed out that LERs increase as the denominators or monocrop values decrease and it is important to assess LERs in the context of minimum acceptable yields, quality and cost effectiveness.

The cost effective advantage of tall corn and soybeans at 60 kg N ha^{-1} was very consistent (Table 3.6) in seasons of both low and high rainfall. The lower cost for N fertilizer and maximum yields of intercropped tall corn at 60 kg N ha^{-1} accounted for the superior cost effectiveness. The contribution of N from soybean nodules at 60 kg N ha^{-1} may have spared soil N for corn. At this intermediate N level the optimal conditions seemed to merge for both plant growth and soybean nodulation. The significant decrease of European corn borer infestation in tall corn intercrops compared to monocrops and at 60 compared to 120 kg N ha^{-1} (Martin et al. 1989), may also have contributed to the cost effectiveness of the tall corn intercrop at 60 kg N ha^{-1}. Most intercrops with applied N (except dwarf corn intercrops in 1985) were more cost effective than the monocropped corn standard. The additive populations of the intercrops resulted in greater net benefits in spite of increased losses from interspecific competition and a higher cost for seed.

Further research should be conducted to compare the dwarf-tall corn mixture to high monocropped corn population densities (133%) as well as to corn-soybean intercrops. Determinations of N_2 fixation of soybeans under several N rates in soybean monocrops and intercrops could test the idea that associated corn reduces inhibition of N_2 fixation by "mopping up" excess fertilizer N. The optimum 60 kg ha^{-1} N rate might be different on soil known to be at medium to low soil N levels.

Actual feed values or cost effectiveness comparisons of intercropped silage should be assessed in feeding trials of dairy or beef cattle. A complete range of determinations of total silage feed value parameters, especially pertaining to energy and protein, could clarify the relative value of corn-soybean intercrops and corn monocrops.

Preface to Section 4

Section 4 is part of the manuscript by Martin et al. (1989) published in the Journal of Economic Entomology. The format has been changed to conform as much as possible to a consistent format within this thesis. All literature cited in this section is listed in the reference section at the end of the thesis. Each table is presented on the page following the first referral to it.

After the demonstration of the agronomic and economic advantages of corn-soybean intercropping in section 3, this section deals with the effect of European corn borer infestation in corn-soybean intercrops. European corn borer infestation of corn is a serious pest problem in eastern Ontario. Therefore, it was felt that it would be prudent to assess the European corn borer infestation levels in the 2 x 2 x 3 factorial outlined in section 3.

Section 4

REDUCTION OF EUROPEAN CORN BORER (LEPIDOPTERA: PYRALIDAE) DAMAGE BY INTERCROPPING CORN WITH SOYBEAN

4.0. Abstract :

Corn (Zea mays L.) and soybean (Glycine max [L.] Merr.) were intercropped for silage in 1985 and 1986 at the Central Experimental Farm, Ottawa to determine effects on yields and the percentage of European corn borer (Ostrinia nubilalis) Hubner infestation. A 2 x 2 x 3 factorial was analyzed with two corn hybrids (dwarf PAG 391134 and tall Coop S259), two corn cropping systems (monocropped and intercropped), and three nitrogen fertilizer levels (0, 60 and 120 kg N ha^{-1}). Intercropping significantly reduced European corn borer infestation in tall corn in 1985 and in both corn hybrids in 1986 Dwarf corn was infested significantly less than tall corn in both years and in both cropping systems. The commonly applied rate of 120 kg N ha^{-1} resulted in the highest European corn borer infestation. Yields and land equivalent ratios (LERs) at 60 kg/N ha were as high as those at 120 kg N ha^{-1}, but European corn borer infestation was significantly less at 60 kg N ha^{-1}. Application of 0 kg N ha^{-1} resulted in the lowest yields and LERs, but European corn borer infestation was not different from levels at 60 kg N ha^{-1}.

4.1. Introduction :

Intercropping has been practiced in the tropics for centuries. Although less common in temperate regions, intercropping, especially with corn (Zea mays L.), beans and squash, was a tradition of North American Indians (Plucknett and Smith, 1986). Recently, intercropping has received more attention based on advantages it may have in modern agriculture. For example, Toniolo et al. (1987), reported that intercrops of corn and soybeans (Glycine Max [L.] Merr.) had higher protein contents than sole corn and dry matter land equivalent ratios (LERs) of up to 1.2.

Intercropping has also been effective in the reduction of pests and diseases. In an intercrop consisting of corn, beans and squash, significantly fewer specialist and generalist beetles were found than in monocrops (Risch and Hansen, 1982). This result was attributed to different overall patterns of beetle movements in intercrops as compared to pure stands. However, Capinera et al. (1985) reported that the effects of intercropping are variable. For example, Mexican bean beetles (Epilachna varivestis Mulsant) and western flower thrips (Frankliniella occidentalis [Pergande]) were more common in homogeneous strips of pinto beans than in bean-sweetcorn intercrops; some insects were unaffected by intercropping, but western corn rootworm (Diabrotica virgifera Leconte) and corn leaf aphid (Rhopalosiphum maidis [Fitch]) were favoured by intercropping. With a mixture of corn and beans, van Rheenan et al. (1980) reported a lower incidence of halo blight, bean common mosaic, anthracnose, common blight, scab, phoma, mildew, bollworm and angular leaf spot, although the opposite effect was noted for white mold and black Systates.

European corn borer, Ostrinia nubilalis (Hubner), has reduced corn yields by amounts of 102 to 466 kg ha^{-1} in North Carolina (Umeozor et al. 1985). Corn plants become more susceptible to disease organisms when injured by European corn borer and the pest should be controlled when 40-50% of the plants have been attacked (Hudon et al. 1982) Raemisch and Walgenbach (1983) found that infestation by first-generation European corn borer reduced silage yields by 14.1 to 14 7% compared with plots treated with cypermethrin. Boivin et al. (1988) found no correlation between percentage of plants infected and yield, although they noted that hand harvesting minimized potential stalk breakage and ear drop losses. Lambert et al. (1987) found that intercropping of corn with red clover reduced damage by European corn borer compared with monocrops in a 2-year field trial. These relationships were consistent for various nitrogen fertilization levels at two field sites.

Here, we compare the percentage of infestation by European corn borer under the cropping systems of monocropping and intercropping with two corn hybrids and soybeans and the application of three levels of nitrogen. Intercropping yield advantages of corn-soybean silage are also assessed in the context of the percentage infestation by European corn borer.

4.2. Materials and Methods :

The trials were situated at the Central Experimental Farm of Agriculture Canada in Ottawa, Ontario on different sites in 1985 and 1986. The experiment was part of a larger intercropping study to compare cropping systems, corn hybrids, soybean varieties, N fertilizer levels, spacing patterns and population densities. All treatments of the incomplete factorial were arranged in a randomized complete block design with four replications. A complete 2 x 2 x 3 factorial was analysed for two corn hybrids (dwarf and tall), two cropping systems (monocropped and intercropped with soybeans), and three N fertilizer levels (0, 60 and 120 kg N ha^{-1}). The hybrids of corn, Coop S259 (tall) and PAG 391134 (dwarf), and 'Maple Arrow' soybeans were planted in mid-May and harvested as whole plants for silage in late September of each year.

The summer of 1985 was relatively dry. Total rainfall in May, June, July, August and September was 68.1, 94.8, 67.2, 71.1 and 46.2 mm, respectively, compared with 164.3, 107.0, 144.4, 99.0 and 167.6 mm of rainfall in the same months of 1986 (Environment Canada 1985, 1986).

The number of corn stalks attacked by European corn borer per plot was expressed as a percentage of the number of stalks sampled at the time of harvest. Stalk infestation was determined by splitting the stalks to observe the presence or absence of European corn borer tunnels inside the stalks and by the characteristic holes seen from the outside of the stalk.

Tall corn was planted at rates of 60,000 plants per ha in the monocrop system and 40,000 plants per ha in an intercrop system. Dwarf corn was planted at recommended monocrop rates of 150,000 plants per ha and at 100,000 plants per ha in an intercrop. Monocropped soybeans were planted at the rate of 500,000 plants per ha and intercropped soybeans were planted at the rate of 334,000 plants per ha. In each case, the lower rate is 67% of the full rate.

Each plot consisted of 12 rows, 40 cm apart and 6.5 m in length. Samples were removed from the central 2.5 m of the middle four rows in each plot; this material was used to assess the dry weight yields of corn and soybeans and the percentage European corn borer infestation. Intercrops with tall corn were planted with corn and beans in alternate rows, whereas intercrops of dwarf corn had corn and bean plants within the same row. This arrangement was selected because the high population of dwarf corn was expected to decrease corn yields from excessive intraspecific competition when grown in 80 cm corn rows. Because hybrid comparisons between tall and dwarf corn were complicated by agronomic yield objectives that require planting monocropped dwarf corn at high populations in narrow rows, effects due to this factor must be interpreted with caution.

Percentage infestation data were analysed by analysis of variance (ANOVA procedure) (SAS Institute Inc. 1982) after an arc sine transformation of the data. Untransformed yield data were also analysed by ANOVA. The significance ($\underline{P} \leq 0.05$) of the main effect of each factor and all possible interactions were considered. When significant differences were found by ANOVA, Duncan's multiple range test was applied for comparisons between two or more means (Steel and Torrie, 1980). All differences reported in this paper are significant unless otherwise stated.

LER values were calculated such that LER = $L_a + L_b$ where L_a is the fraction of the yield of intercropped corn relative to the yield of monocropped corn and L_b is the fraction of intercropped beans relative to the yield of monocropped beans (Mead, 1986). Because an LER is a ratio of monocrop and intercrop values, cropping systems cannot be evaluated with an LER as the response variable. Therefore, LERs were compared by ANOVA in a 2 x 3 factorial of the two levels of the corn hybrid factor and the three levels of N. Application of the ANOVA procedure for LERs is justified because the denominators of respective ratios were the same in every LER calculation. Soybeans were monocropped without nitrogen and the corn monocrop value was taken as the mean of the three nitrogen level monocrops according to the first method of standardization of Oyejola and Mead (1982). The monocropped soybeans were included in the randomization of the overall study but were only used to calculate LERs in this experiment.

4.3. Results :

Except for the response variable of European corn borer infestation in 1985, for which the interaction of corn hybrids and cropping systems was significant (Table 4.1), interactions between factors were not significant ($\underline{P} \geq 0.05$). Therefore, the simple effects were analyzed for this variable in 1985 for each cropping system at each level of corn hybrid. All values of infestation in tall corn were greater than any value of dwarf corn; therefore, the main effects of corn hybrids were obviously different. In all other cases in 1985 and 1986, main effects were analyzed.

The percentage of corn stalk infestation was significantly greater in monocropped (70%) tall corn than in intercropped (33%) tall corn in 1985, but the effect of intercropping was not significant for dwarf corn (16% in monocropped and 13% in intercropped corn) (Table 4.1). In 1986, intercropping significantly reduced the percentage infestation from 43% to 33%. These means were combined for both levels of corn

Table 4.1. (a) Percentage of European corn borer infestation in 1985 and 1986.

		% infestation					
		1985			1986		
CH	CS	ON	60N	120N	ON	60N	120N
tall	mono	68a A	68a A	74a A	46a B	48a B	59a A
tall	inter	30b A	40ab A	30b A	33ab B	36ab B	63a A
dwarf	mono	12bc A	16bc A	20b A	21bc B	32ab B	54a A
dwarf	inter	6c A	9c A	24b A	17c B	21b AB	29b A

N, kg ha^{-1} of nitrogen; CH, corn hybrid; CS, cropping system.

[a] Means in a row followed by the same upper case letter and means in a column followed by the same lower case letter are not significantly different ($P > 0.05$; Duncan's multiple range test). The differences were determined by analysis of data after an arc sine transformation.

Table 4.1. (b) Analysis of variance of percentage infestation in 1985 and 1986.

Source of		1985		1986	
variation	df	F-value	P > F	F-value	P > F
Model	14	5.64	0.0001	4.15	0.0004
Replicates	3	2.28	0.0976	0.38	0.7662
N	2	0.86	0.4306	11.32	0.0002
CH	1	45.11	0.0001	22.11	0.0001
CS	1	14.01	0.0007	7.69	0.0091
N * CH	2	0.60	0.5530	0.40	0.6714
N * CS	2	0.32	0.7275	0.04	0.9624
CH * CS	1	7 98	0.0079	1.18	0.2845
N * CS * CH	2	0.69	0.5084	1.25	0.2985

N, nitrogen; CH, corn hybrid; CS, cropping system.

hybrids and all nitrogen levels.

The main effect of nitrogen, in 1986, was 51% infestation at 120 kg N ha^{-1}, which was greater than 34% at 60 kg N ha^{-1} or 29% at 0 kg N ha^{-1}. However, this trend was not significant in 1985. Tall corn was significantly more susceptible to European corn borer infestation than dwarf corn in in each cropping system, in 1985. The main effect of corn hybrid, in 1986, showed a higher infestation of 48% in tall corn contrasted to 29% infestation in dwarf corn.

In 1985, corn silage yield was increased by nitrogen, as a main effect, from 6963 kg ha^{-1} at 0 kg N ha^{-1} to 9477 kg ha^{-1} at 60 kg N ha^{-1} but there was no further significant increase when 120 kg N ha^{-1} were applied (Table 4.2). The latter is normal agronomic practice Similarily, the total silage yield improved from 7763 kg ha^{-1} to 10214 kg ha^{-1} by applying 60 kg N ha^{-1} but did not improve more when 120 kg N ha^{-1} were applied. The cropping system main effect resulted in a higher monocrop corn yield (9941 kg ha^{-1}) than the intercrop corn yield (7315 kg ha^{-1}) or the total intercrop yield (8835) kg ha^{-1}). The corn hybrid main effect was not significant.

Main effect analysis, in 1986, of corn silage and total silage yields showed differences similar to those of 1985 (Table 4.3). Yields of corn silage and total silage were increased from 9357 kg ha^{-1} and 10696 kg ha^{-1}, respectively, at 0 kg N ha^{-1}, to 12657 kg ha^{-1} and 13894 kg ha^{-1}, respectively, at 60 kg N ha^{-1}. There was no further yield response due to 120 kg N ha^{-1}. Monocropped corn (13104 kg ha^{-1}) yielded higher than intercropped corn (9841 kg ha^{-1}) or intercropped total silage (12332 kg ha^{-1}). No differences were determined due to the corn hybrids.

Table 4.2. (a) Yield (dry wt.) of corn silage and total silage (corn and soybeans) in 1985.

		silage yield (kg ha^{-1})					
		0N		60N		120N	
CH	CS	corn (soy)	total	corn (soy)	total	corn (soy)	total
tall	mono	7591ab B	7591a	10319ab A	10319a	10398ab A	10398a
tall	inter	5627b B	--	8868bc A	--	8364ab A	--
		(1700)	7327a B	(1485)	10353ab A	(1594)	9958a A
dwarf	mono	9127a A	9127a	11450a A	11450a	10762a A	10762a
dwarf	inter	5506b B	--	7272c AB	--	8254b A	--
		(1502)	7008a B	(1461)	8733b AB	(1377)	9631a A

N, kg ha^{-1} of nitrogen; CH, corn hybrid; CS, cropping system.

[a] Means in a row followed by the same upper case letter and means in a column followed by the same lower case letter are not significantly different ($P > 0.05$; Duncan's multiple range test).

Table 4.2. (b) Analysis of variance of silage yield in 1985.

Source of variation	df	Corn Silage F-value	Corn Silage P > F	Total Silage F-value	Total Silage P > F
Model	14	4.41	0.0002	2.72	0.0090
Replicates	3	1.40	0.2592	1.52	0.2264
N	2	11.75	0.0001	11.55	0.0002
CH	1	0.17	0.6819	0.07	0.7909
CS	1	29.23	0.0001	5.36	0.0270
N * CH	2	0.32	0.7299	0.28	0.7586
N * CS	2	0.13	0.8750	0.12	0.8865
CH * CS	1	2.78	0.1051	3.41	0.0738
N * CS * CH	2	0.45	0.6426	0.39	0.6809

N, nitrogen; CH, corn hybrid; CS, cropping system.

Table 4.3. (a) Yield (dry wt.) of corn silage and total silage (corn and soybeans) in 1986.

		silage yield (kg ha^{-1})					
		0N		60N		120N	
CH	CS	corn (soy)	total	corn (soy)	total	corn (soy)	total
tall	mono	10423a A	10423a	14408a A	14408a	13946a A	13946a
tall	inter	8691b B	--	10760b A	--	10605b A	--
		(2483)	11174a B	(2453)	13213a A	(2392)	12997a A
dwarf	mono	10995a B	10995a	14684a A	14684a	14166a A	14166a
dwarf	inter	7319b B	--	10775b A	--	10896b A	--
		(2874)	10193a B	(2496)	13271a A	(2246)	13142a A

N, kg ha^{-1} of nitrogen; CH, corn hybrid; CS, cropping system.

[a] Means in a row followed by the same upper case letter and means in a column followed by the same lower case letter are not significantly different ($P > 0.05$; Duncan's multiple range test).

Table 4.3. (b) Analysis of variance of silage yield in 1986.

Source of variation	df	Corn Silage *F*-value	Corn Silage *P* > *F*	Total Silage *F*-value	Total Silage *P* > *F*
Model	14	14.08	0.0001	6.56	0.0001
Replicates	3	0.57	0.6419	0.68	0.5686
N	2	43.44	0.0001	39.46	0.0001
CH	1	0.00	0.9986	0.02	0.8817
CS	1	102.83	0.0001	5.70	0.0228
N * CH	2	0.40	0.6759	0.15	0.8586
N * CS	2	0.93	0.4031	1.41	0.2577
CH * CS	1	1.22	0.2767	0.91	0.3477
N * CS * CH	2	0.94	0.4017	0.53	0.5940

N, nitrogen; CH, corn hybrid; CS, cropping system.

The application of 60 kg N ha^{-1}, as a nitrogen main effect, increased LERs from 0.96 to 1.18, in 1985, and from 1.03 to 1.21, in 1986 (Table 4.4). No further advantage was obtained by applying 120 kg N ha^{-1}. With the exception of dwarf corn in 1985, all LER values at 60 and 120 kg N ha^{-1} were significantly greater than 1.0. LERs were not different because of the corn hybrid main effect in either year.

4.4. Discussion :

Intercropping significantly decreased the percentage of European corn borer infestation in tall corn in 1985 and in both tall and dwarf corn in 1986. These effects are similar to those observed previously with corn and clover intercrops (Lambert et al. 1987). Guthrie (1987) suggested a corn hybrid with European corn borer resistance that is present during the whole life of the plant would not be possible without unacceptable yield reductions because only 2 or 3 of 12 genes apparently are common to resistance to the insect's first generation and second generation. Results of our study demonstrate that intercropping can decrease infestation to < 40% and can provide a complementary strategy to resistance.

The significantly higher percentage of European corn borer infestation in monocropped corn did not correspond with lower yields. However, the highest yielding component crop of an intercrop usually yields better without the competition of an associated crop (Gliessman, 1986). In our experiments, competition from soybeans seemed to be more detrimental to corn yields than European corn borer infestation, although it is reasonable to assume that reduced infestation resulted

Table 4.4. (a) LER of corn and soybean in 1985 and 1986.

	LER					
	1985			1986		
CH	0N	60N	120N	0N	60N	120N
dwarf	0.93a B	1.09a AB	1.17a A	1.00a B	1.21a A	1.18a A
tall	0.99a B	1.26a A	1.24a A	1.05a B	1.20a A	1.18a A

N, kg ha^{-1} of nitrogen; CH, corn hybrid.

[a] Means in a row followed by the same upper case letter and means in a column followed by the same lower case letter are not significantly different (P > 0.05; Duncan's multiple range test).

Table 4.4. (b) Analysis of variance of LER in 1985 and 1986.

Source of variation	df	1985 F-value	1985 P > F	1986 F-value	1986 P > F
Model	8	3.24	0.0237	3.05	0.0299
Replicates	3	1.28	0.3158	0.52	0.6738
N	2	8.89	0.0028	11.13	0.0011
CH	1	3.44	0.0833	0.13	0.7201
N * CH	2	0.43	0.6558	0.23	0.7970

N, nitrogen; CH, corn hybrid.

in less reduction of intercropped corn yields than might otherwise have occurred.

Hudon et al. (1982) reported that European corn borer moths are attracted by taller corn plants where more eggs are laid. Our results were similar: dwarf corn was infested less than tall corn in both years and in both cropping systems. The maximum infestation of dwarf corn, considerably lower than in tall corn, resulted in a narrower range of infestation. Differences in infestation because of intercropping, particularly in 1985, were more difficult, to detect when the dwarf corn was under moisture stress as well as the normal stress of a high population. Umeozor et al. (1985) also observed lower corn yields and noted a lower reduction of yields caused by European corn borer in a dry year compared with a wet year.

The increase of European corn borer infestation from 60 to 120 kg N ha^{-1} may be related to more lush leaf tissue at the higher nitrogen rate. Most first-generation larvae feed on leaf tissue in the moist area deep in the whorl of corn plants. Resistance to feeding is in the form of antibiosis or resistance to leaf feeding (Dharmalingam et al. 1984). Antibiosis may be a function of less palatable leaves at lower nitrogen rates. Cannon and Ortega (1966) found that European corn borer leaf feeding and the number of larvae surviving increased with increasing rates of applied nitrogen on a susceptible corn hybrid.

Our observations that yields and LERs did not change between 60 and 120 kg N ha^{-1} and that the highest European corn borer infestations were found at 120 kg N ha^{-1} suggest that the failure of yields to increase between 60 and 120 kg N ha^{-1} was due, at least in part, because of higher infestations at 120 kg N ha^{-1}. Alternatively, nitrogen may not have been a limiting factor beyond 60 kg N ha^{-1}. Although data for yields of corn without infestation were not available for comparison, monocrops of corn without European corn borer infestation might be expected to have shown more response to nitrogen than we observed in the presence of infestation. Infestation weakens stalks causing lodging and breakage.

LER values are important indicators of intercropping usefulness, especially when both crops are important for cash sales or in a balanced feed ration. An LER of 1.2 shows that, if corn and soybeans were monocropped, 1.2 ha would be required to achieve the same yields as from 1.0 ha of the intercrop. Without the beneficial reduction of European corn borer infestation because of intercropping, the ratio L_a (intercropped corn over monocropped corn) might have been lower and thus decreased the overall LER advantage.

In summary, European corn borer infestation was reduced in most intercropping treatments. Dwarf corn was infested significantly less than tall corn in both years and in both cropping systems. European corn borer infestation responded positively to an increase of nitrogen from 60 to 120 kg N ha^{-1}. These three effects were observed with satisfactory yields and LERs greater than one. The mechanisms underlying these effects merit further investigation.

Preface to Section 5

Section 5 is part of the manuscript by Martin et al. (1990b) submitted to the Canadian Journal of Plant Science. The format has been changed to conform as much as possible to a consistent format within this thesis. All literature cited in this section is listed in the reference section at the end of the thesis. Each table is presented on the page following the first referral to it.

After the demonstration of the agronomic and economic advantages of corn-soybean intercropping in section 3, this section focuses on the effects of N_2 fixing nodules and spacing patterns in corn-soybean intercrops. The effects of N_2 fixation in soybean nodules were expected to favourably influence yield and protein levels in corn-soybean intercrops. This question is addressed in section 5 by comparing nodulating and nonnodulating soybean in corn-soybean intercrops. Plant spacing patterns can have effects in monocrops but in intercrops the effects can be more pronounced. In section 5, corn-soybean intercrop spacing patterns are compared at different levels of other factors such as population density and nitrogen. There is also a comparison between corn and soybean grown for seed yield in an intercrop and a stripcrop.

Section 5

INTERCROPPING CORN AND SOYBEAN FOR HIGH-PROTEIN SILAGE IN A COOL TEMPERATE REGION: EFFECTS OF NODULATION AND SPACING PATTERNS.

5.0. Abstract :

Production by corn-soybean intercrops can be reduced or enhanced by competitive and complementary factors, respectively. In this study, the effects of soybean nodulation and spacing patterns on yield were examined. In 1985 and 1986, nodulating and nonnodulating soybean were grown in a mixture and were intercropped with dwarf corn at two spacing patterns. In 1986, tall corn was also intercropped with nodulating soybean at two spacing patterns and at two population densities In 1987, corn and soybean were intercropped and stripcropped.

In a year of low rainfall (1985), nodulating soybean yielded more than nonnodulating soybean when the two were grown in a soybean mixture and when each was intercropped with dwarf corn. The higher nodulating soybean yields corresponded to lower yields of the associated crops No differences were observed in soybean or corn yields due to within- or between-row spacing patterns. In 1986, nonnodulating soybean and dwarf corn had higher protein and yield levels when grown in association with nodulating soybeans. Total intercrop yields were not affected by spacing pattern or population density but tall corn yields were higher in rows of standard widths. In 1987, the total crop yield and Land Equivalent Ratio of the intercrop was higher than the strip-crop. These data indicate that soybean nodulation can improve yields

and confer benefits to associated plants and that corn-soybean intercrops tend to be more productive when all corn row widths are equidistantly spaced.

5.1. Introduction :

The advantages of intercropping corn (Zea mays L.) and soybean (Glycine max [L.] Merr.) have been well documented (Yunasa, 1989; Putnam et al. 1985; Mohta and De, 1980 and Dalal, 1977). Corn-soybean intercrops are also succesful in short growing seasons near the northern limits for economical corn and soybean production (Martin et al. 1990a). It is important to determine the optimum growing conditions of intercrops under such climatic conditions.

Intercropping benefits appear to be largely due to the nodule contribution of component legume crops (Hiebsch and McCollum, 1987 and Ofori and Stern, 1987). Comparisons of nodulating and nonnodulating soybean can determine nodulation effects. A nonnodulating soybean variety had improved seed yield, protein yield, weight per seed and seed numbers when grown with an actively nodulating variety (Vest, 1971). Burton et al. (1983), found that a nonnodulating soybean cultivar had an average 38% yield increase and a 56% total protein increase when it was grown with each of six nodulating cultivars rather than as a monocrop. These increases were even higher in association with its nodulating isoline. Elmore and Jackobs (1986), measured lower N yields in sorghum grown with nonnodulating soybean than in sorghum grown with nodulating soybean. They attributed the difference to transfer of nitrogen from nodulated soybean.

The spacing pattern should be arranged to reduce both interspecific and intraspecific competition. A corn spacing pattern of wider intra-row spaces with three corn plants per hill allowed improved intercropped soybean yields with little effect to the corn (Chiu and Shibles, 1984). However, Van Kessel and Roskoski (1988) noted that closer inter-row spacing increased yields of maize and cowpea. Mohta and De (1980), found that intercropping did not significantly influence corn yields but soybean yields were decreased less when grown between wide corn rows than between narrow corn rows. Fisher et al. (1987) reported higher cowpea yields and LERs when corn and cowpeas were grown in alternate rows than when both were grown in the same row. Pendleton et al. (1963) planted a strip-crop of six, 60 cm corn rows alternating with six, 60 cm soybean rows and found that the 20% corn yield increase was offset by the 20% soybean yield decrease.

The objective of this work was to test the effects of nodulation and plant spacing patterns on corn-soybean intercrops, in Ottawa, Ontario at 45^{0} N latitude. In addition, the factors of soybean genotype, N fertilizer level and plant population density were included in some factorials. The effects on corn and soybean yield, crude protein and LERs were evaluated.

5.2. Materials and Methods :

Two similar experiments were conducted in 1985 and 1986, at the Central Experimental Farm of Agriculture Canada in Ottawa. The soil was a Granby sandy loam (Typic Haplaquoll). The 1986 site was about 1 km from the 1985 site. Each site was fall-plowed and cultivated twice the following spring, prior to seeding. Weeds were controlled by a pre-emergent application of metolachlor and linuron at 2.2 and 1.1 kg a.i. ha^{-1}, respectively. Weeds were also removed by hand, when necessary.

The summer of 1985 was relatively dry. Total rainfall in May, June, July, August and September was 68.1, 94.8, 67.2, 71.1 and 46.2 mm, respectively, compared with 164.3, 107.0, 144.4, 99.0 and 167.6 mm of rainfall in the same months of 1986 (Environment Canada, 1985 and 1986).

The experiments were designed to compare cropping systems, corn hybrids, nodulation effects, plant spacing patterns, soybean genotypes, N fertilizer levels, and plant population densities. Each experiment consisted of an incomplete factorial of 24 treatments in 1985 and 30 treatments in 1986. The treatments were arranged in a randomized complete block design with four replications. There were several treatment subsets which formed independent complete factorials.

The plots were planted in mid-May and harvested in late September, in both years. Wet weight yields were determined from the centre 2.5 m of the middle four rows of 12 row plots or the middle two rows of six row plots. A representative subsample of 3 - 4 corn plants and 10 - 20 soybean plants from each plot was weighed in the field at the same time, oven-dried at 80° C for at least 72 hrs., and weighed again to determine the moisture content. The whole plants were chopped with a corn silage chopper and then ground in a Wiley mill (20 mesh sieve). The concentration of total nitrogen was determined on ground tissue by Kjeldahl analysis (Tecator, Kjeltec 1030 Auto Analyzer). Crude protein was calculated as 6.25 times percent N.

Biomass yields, crude protein concentrations and crude protein yields were analysed by analysis of variance (SAS Institute Inc., 1982). The significance ($P \leq 0.05$) of the main effect of each factor and all possible interactions were considered. When significant differences were found, a protected LSD test or a contrast with 1 degree of freedom was applied for comparisons between means (Steel and Torrie, 1980).

LER values were calculated as LER = $L_a + L_b$ where L_a is the fraction of the yield of intercropped corn relative to the yield of monocropped corn and L_b is the fraction of intercropped soybean relative to the yield of monocropped soybean (Mead, 1986). Since the level of management should be as similar as possible for each cropping system (Willey, 1979), each L_a was calculated with the same level of N for intercropped and monocropped corn. Every L_b was calculated with monocropped soybean at 0 kg N ha^{-1}, the only N rate used for monocropped soybean.

Ammonium nitrate applications were at 0, 60 or 120 kg N ha^{-1}, two to three weeks after planting. Measured volumes of the fertilizer were applied in shallow trenches, three to five cm deep and 10 to 15 cm from the corn rows. The fertilizer was covered immediately after application. When 60 kg N ha^{-1} were added all the fertilizer was placed in a trench on one side of the corn row. When 120 kg N ha^{-1} were added there were two trenches per corn row, one on each side.

Monocropped plant populations were 60,000 plants ha^{-1} for tall corn (Coop S259) in 80 cm rows, 150,000 plants ha^{-1} for dwarf corn (PAG 391134) in 40 cm rows and 500,000 plants ha^{-1} for soybeans in 40 cm rows. Most intercrops were planted with corn and soybean, each at 67% of their monocrop population (P1). P1 also applied to the mixture of nodulating and nonnodulating soybean. In 1986, a lower intercrop population density with tall corn and soybean, each at 50% of their monocrop populations (P2) was compared to P1.

In both years, the Maple Arrow (MA) nodulating cultivar and a selection from a cross of Evans and a nonnodulating isoline of Harosoy were planted. The nonnodulating strain was intended as a check for N transfer from nodulating soybean to corn and as a check for general intercropping advantages attributed to legume nodulation. In 1985, Nattawa, a semi-wild nodulating soybean type, was also included to assess the value of its vining habit in an intercrop. A commercial granular inoculant of Bradyrhizobium japonicum, (Nitragin Co.) was applied in the drill row with all soybean varieties at planting.

Four spacing patterns were tested in 1985 and 1986 (Table 5.1). In 1985, the higher intra-row competition of S1 was compared to the lower intra-row and higher inter-row competition of S2. In both years, intercrops with tall corn were planted with corn and soybean plants in alternate rows (S3), whereas intercrops with dwarf corn had corn and soybean plants in the same rows (S1). The dwarf corn arrangement was selected because excessive intraspecific competition was expected of the high population of dwarf corn when grown in 80 cm rows. To achieve adequate yields with small cobs and short statured plants, dwarf corn must be planted at a population 2.5 times more dense than tall corn In 1986, the two intercropped corn hybrids at 60 kg N ha^{-1}, were also planted in each other's spacing pattern. Dwarf corn and nodulating soybean were planted at S3 and tall corn and soybean were planted at S1. S4 spacing patterns (Table 5.1), in 1986, were designed to allow more sunlight to reach the soybean understory and to create an edge effect with the upper part of the corn.

Table 5.1. Spacing pattern definitions

Designation	Definition
S1	corn and soybean within the same rows, 40 cm apart.
S2	corn and soybean in alternate rows, 20 cm apart.
S3	corn and soybean in alternate rows, 40 cm apart.
S4	corn in paired rows, 40 cm apart; soybean in two rows, each 20 cm outside a corn row; space of 80 cm between each four row combination.

In 1987, two spacing patterns (intercropping and strip cropping) of corn and soybean were compared on a farm scale. A level, four hectare field of well-drained, sandy loam soil with no residual herbicide, was selected near Edwards in Eastern Ontario. Since there was extensive ground coverage with 15-20 cm high quack grass, Round-Up (glycophosphate), was applied at the rate of 2.5 L ha^{-1} on May 5, 1987. This provided effective quack grass control. The field was disked and cultivated three times, May 16 - 19.

The 1987 trial was planted on May 21 with J82 soybeans and JX3 medium round corn by a John Deere 7000 4-row corn planter. The four treatments each had 16 rows, 76 cm wide and 152 m long. The treatments were randomly arranged within each of the four replications. Fertilizer was incorporated in bands beside seed rows, with the corn planter. The powdered peat inoculant, (Bradyrhizobium japonicum) was applied as a slurry mix (1 bag of inoculant and 250 ml of refined sugar in 1 L of water) to each 120 kg of soybean seed. On May 26, metolachor and linuron were applied at 2.2 and 1.1 kg a.i. ha^{-1}, respectively.

In 1987, treatment 1 (monocropped corn), was planted at 65,000 seeds ha^{-1} and fertilized with 140 kg ha^{-1} of 8-38-15 and 140 kg ha^{-1} of 46-0-0. In treatment 2 (intercropped corn and soybean) the corn and soybean seeds were thoroughly mixed and planted within the same rows. The planter was adjusted to plant the seed mixture at rates of 48,750 corn seeds ha^{-1} (75% of 65,000) and 250,000 soybean seeds ha^{-1} (50% of 500,000). Fertilizer was applied to treatment 2 at the same rate and proportion as for treatment 1. Treatment 3 (stripcropping of four corn rows alternated with four soybean rows), was planted at 47,000 corn seeds ha^{-1} and 250,000 soybean seeds ha^{-1}. The rate for the corn strip was intended to be the same as for the corn component in treatment 2 but the planter could only be set at a higher or a lower rate and the lower rate was chosen. The fertilizer rate for the corn strips was 75 kg ha^{-1} of 8-38-15 and 280 kg ha^{-1} of 46-0-0. The fertilizer rate for the soybean strips was 205 kg ha^{-1} of 8-38-15. Therefore, the entire treatment had 140 kg ha^{-1} of 8-38-15 and 140 kg ha^{-1} of 46-0-0, the same as in treatments 1 and 2. Treatment 4 (monocropped soybean), was planted at 500,000 seeds ha^{-1} and fertilized with 205 kg ha^{-1} of 8-38-15. Bean cups were used on the planter in treatments 2 and 4 and for the soybean strips in treatment 3. The 76 cm rows were maintained in all treatments because the planter was fixed at this width.

Harvesting to determine weights was done by hand on October 10, 1987. The remainder of the field was harvested with a forage harvester on October 20 and the silage was fed to beef cattle. The subplots were 10 m lengths of the centre rows of each treatment and each subplot was positioned between two straight lines running perpendicular to the rows across the field. Dry grain weights of corn and soybean were used to calculate yields ha^{-1} and LERs. Since present harvesting equipment does not permit separation of corn grain from soybean seeds in an intercrop, the grain and seed yield was evaluated to determine whether intercropping land use efficiency could also be seen in stripcrops, which can be harvested separately. LERs were tested in an ANOVA procedure. Since the denominator of each L_a was the same and the denominator of each L_b was the same, this was a valid procedure (Oyejola and Mead, 1982).

5.3. Results :

In both years, yields were not significantly different between monocropped nodulating and nonnodulating soybean genotypes (Table 5.2). In the mixture of nodulating and nonnodulating soybean, they competed equally in 1986, but in the dry year of 1985, nodulating soybean produced about three times the yield of nonnodulating soybean. The crude protein yield of nodulating soybean was also higher than nonnodulating soybean in 1985 but the difference was not significant in 1986. However, the nonnodulating monocrop yielded significantly less protein than the nodulating monocrop or the soybean mixture, in 1986. Monocropped nonnodulating soybean also had a lower protein concentration, in both years, than the nodulating monocrop or the soybean mixture. In 1986, the protein concentration of nonnodulating soybean was significantly increased when intercropped with nodulating soybean. Within the soybean mixture, nodulating soybean had a higher protein concentration than nonnodulating soybean in both years.

In 1985, yields of the monocropped semi-wild nodulating genotype, Nattawa, were numerically but not statistically lower than Maple Arrow or the nonnodulating strain (Table 5.2). The protein concentration of Nattawa was significantly higher than that of nonnodulating and Maple Arrow soybean monocrops and similar to that of the soybean mixture. Protein yields were not different between soybean genotypes.

In 1985, at both 0 and 60 kg N ha^{-1}, Nattawa, intercropped with dwarf corn, yielded significantly less than Maple Arrow intercropped with dwarf corn (Table 5.3). At 120 kg N ha^{-1}, Nattawa yielded as high as Maple Arrow. The 1.22 LER of the intercrop with Nattawa soybean at

Table 5.2. Dry weight yields and crude protein concentrations and yields of soybean for silage in 1985 and 1986.

			1985			1986	
	Treatment	Nod	NN	Total	Nod	NN	Total
Yield (kg ha^{-1})	(Nod-NN)	2702A	989B	3690a	3178A	3559A	6736a
	(Nod)	4045	--	4045a	6447	--	6447a
	(NN)	--	4170	4170a	--	5816	5816a
	(Nat)	--	--	3214a	--	--	--
Protein yield (kg ha^{-1})	(Nod-NN)	487A	133B	620a	638A	418A	1056a
	(Nod)	612	--	612a	1187	--	1187a
	(NN)	--	514	514a	--	561	561b
	(Nat)	--	--	596a	--	--	--
Protein concentration (%)	(Nod-NN)	17.99A	13.38aB	16.78ab	20.00A	11.69aB	15.73a
	(Nod)	15.01	--	15.01b	18.43	--	18.43a
	(NN)	--	12.09a	12.09c	--	9.48b	9.48b
	(Nat)	--	--	18.45a	--	--	--

Nod - nodulating Maple Arrow soybean; NN - nonnodulating soybean; Nat - nodulating Nattawa soybean. Means in a column, followed by the same lower case letter or means in a row followed by the same upper case letter are not significantly different ($p < 0.05$, Protected LSD).

Table 5.3. Dry weight biomass yields (kg ha^{-1}) and LERs of intercropped dwarf corn and three soybean genotypes at three levels of nitrogen and two spacing patterns in 1985.

					Biomass yield			
Treatment	Soybean	Corn	Total	LER	Soybean	Corn	Total	LER
		0N-S1				60N-S1		
Dwarf-Nod	1502a	5506a	7008a	0.97	1461a	7272b	8733b	1.00
Dwarf-NN	782b	6406a	7188a	0.89	983b	9508a	10491a	1.0
Dwarf-Nat	941b	6178a	7119a	0.97	956b	8460ab	9416ab	1.04
		120N-S1				60N-S2		
Dwarf-Nod	1377a	8254a	9631a	1.11	1509a	6631a	8140a	0.95
Dwarf-NN	--	--	--	--	1226a	9205a	10431a	1.10
Dwarf-Nat	1402a	8467a	9869a	1.22	--	--	--	--

Main effects

Treatment	Soybean	Corn	Total	Treatment	Soybean	Corn	Total
Soy genotype effects averaged over 0N, 60N and 120N at S1				Soy genotype effects averaged over 0N and 60N at S1			
Dwarf-Nod	Int	7011a	8457a	Dwarf-Nod	1482a	6389b	7871b
Dwarf-Nat	Int	7702a	8801a	Dwarf-NN	882b	7957a	8839a
Soy genotype effects averaged over S1 and S2 at 60N				Spacing pattern effects averaged over Dwarf-Nod and Dwarf-NN at 60N			
Dwarf-Nod	1485a	6951b	8436b	S1	1222a	8390a	9612a
Dwarf-NN	1104b	9357a	10461a	S2	1368a	7918a	9285a

N = kg N ha^{-1}; Nod = nodulating Maple Arrow soybean; NN = nonnodulating soybean; Nat = nodulating Nattawa soybean; S1 and S2 defined in Table 1; Int = significant interaction ($p < 0.05$) of the main effects; means in a column followed by the same letter are not significantly different ($p < 0.05$, protected LSD).

120 kg N ha^{-1} was largely due to an L_b increase from 0.30 at 60 kg N ha^{-1} to 0.44 at 120 kg N ha^{-1}. Dwarf corn yields and total yields were not affected by soybean genotype in this factorial.

In 1985, nodulating soybean yields were higher than nonnodulating soybean yields in intercrops with dwarf corn at 0 and 60 kg N ha^{-1} (Table 5.3). However, dwarf corn yields were higher in intercrops with nonnodulating soybean averaged over 0 and 60 kg N ha^{-1}, presumably because of less competition from nonnodulating than from nodulating soybean. Corn protein yields and concentrations were not different between intercrops with nodulating or nonnodulating soybeans (data not shown in tables). The total yields followed the same trend as corn yields with the same main effect significant differences.

In 1986, nodulating and nonnodulating soybeans were intercropped with dwarf corn at 0, 60 and 120 kg N ha^{-1}. At 0 kg N ha^{-1}, the nodulating soybean biomass and protein yields were higher than those of nonnodulating soybean (Table 5.4). Nonnodulating soybean biomass and protein yields were higher at 60 and 120 kg N ha^{-1}. Dwarf corn biomass and protein yields were about the same in association with either soybean genotype at 0 kg N ha^{-1}. At 60 or 120 kg N ha^{-1} and averaged over the three N levels, dwarf corn had higher biomass and protein yields when intercropped with nodulating rather than with nonnodulating soybean. The total biomass and total protein yields of the intercrops were greater with nodulating soybean than with nonnodulating soybean at each N level. The only nonsignificant difference in total yields was the total biomass yield at 120 kg N ha^{-1}. The difference in total protein between nodulating and nonnodulating soybean intercrops decreased as the N level increased. The protein LER (1.45) of the

Table 5.4. Dry weight biomass and protein yields (kg ha^{-1}) and LERs of intercropped dwarf corn and two soybean genotypes at three levels of nitrogen at the S1 spacing pattern in 1986.

	Biomass yield				Protein yield			
Treatment	0N	60N	120N	Soy main effect	0N	60N	120N	Soy main effect
Soybean								
Dwarf-Nod	2874a	2496b	2245b	Int	497a	406a	466a	Int
Dwarf-NN	1927b	3285a	3613a	Int	171b	364a	496a	Int
Dwarf corn								
Dwarf-Nod	7319a	10775a	10895a	9663a	494a	785a	810a	696a
Dwarf-NN	6856a	8289b	8461b	7869b	416a	575b	622b	538b
Total of corn and soybean								
Dwarf-Nod	10193a	13272a	13141a	12202a	992a	1191a	1275a	Int
Dwarf-NN	8783b	11575b	12074a	10811b	586b	940b	1117b	Int
LER								
Dwarf-Nod	1.11	1.12	1.12	--	1.16	1.08	1.12	--
Dwarf-NN	0.96	1.13	1.22	--	0.92	1.19	1.45	--

N = kg N ha^{-1}; Nod = nodulating Maple Arrow soybean; NN = nonnodulating soybean, S1 defined in Table 1; Int = significant interaction ($p < 0.05$) of the main effects; means in a column followed by the same letter are not significantly different ($p < 0.05$, 1 df contrast or protected LSD for main effects).

dwarf-nonnodulating intercrop at 120 kg N ha^{-1} was exceptionally high because the denominator of the L_b ratio was a low value based on the yield of monocropped nonnodulating soybean at 0 kg N ha^{-1} (Table 5.2). Furthermore at 120 kg N ha^{-1}, intercropped nonnodulating soybean responded with a protein yield numerically higher than that of intercropped nodulating soybean (Table 5.4).

In 1985, the S1 and S2 spacing patterns were contrasted in intercrops of dwarf corn with nodulating and nonnodulating soybeans at 60 kg N ha^{-1}. No differences were observed in soybean yield, corn yield or total yield due to these spacing patterns (Table 5.3). The soybean genotype main effect was higher for nodulating soybean. Corn yields and total yields, averaged over S1 and S2, were lower in the intercrop with nodulating soybean than the intercrop with nonnodulating soybean. In 1986, the soybean yield was significantly higher and the corn yield was significantly lower at S4 compared to the S3 spacing pattern, averaged over P1 and P2 at 0N (Table 5.5). The total yield was not significantly affected by these spacing patterns. LERs indicated that more efficient productivity was possible with S3. The intercrop at P2 and S3 with an LER of 1.25, maintained a respectable yield for corn at 0 kg N ha^{-1} (8021 kg ha^{-1}) and also had a high intercropped soybean yield (3088 kg ha^{-1}). There was no effect of population density in this factorial but there was an insignificant trend toward higher soybean yields with the lower corn population at P2.

In 1986, the yield of nodulating Maple Arrow soybean intercropped with tall corn was not different between 0 and 60 kg N ha^{-1} or between S3 and S4 spacing patterns (Table 5.5). The corn yield was higher at

Table 5.5. Dry weight biomass yields (kg ha^{-1}) and LERs of intercropped tall corn and nodulating Maple Arrow soybean at two levels of nitrogen, two spacing patterns and two population densities, in 1986.

	Biomass yield				Main effects			
Trt	Soybean	Corn	Total	LER	Trt	Soybean	Corn	Total
		0N-P1			S effects averaged over P1 and P2 at 0N			
S3	2483b	8691a	11174a	1.22	S3	2786b	8356a	11142a
S4	3319a	5979b	9765a	1.10	S4	3549a	6095b	9857a
		0N-P2			S effects averaged over 0N and 60N at P1			
S3	3088b	8021a	11109a	1.25	S3	2468a	9726a	12194a
S4	3712a	6181a	9902a	1.17	S4	2959a	7706b	11048a
		60N-P1			P effects averaged over S3 and S4 at 0N			
S3	2453a	10760a	13213a	1.13	P1	2842a	7528a	10704a
S4	2689a	9001b	11690a	1.04	P2	3405a	7101a	10506a

N = kg N ha^{-1}; Nod = nodulating Maple Arrow soybean; S = Spacing pattern; S3 and S4 defined in Table 1; P = population density; P1 = 67% Tall, 67% Nod; P2 = 50% Tall, 50% Nod; means in a column followed by the same letter are not significantly different ($p < 0.05$, 1 df contrast or protected LSD for main effects).
Note: Missing values for soybean in rep 1 and corn in rep 2 of Tall-Nod 0N at S4

S3 than at S4 in these treatments. The 1.22 LER of the intercrop at 0 kg N ha^{-1} at the regular P1 population density was a reflection of the high S3 corn yield. Total yields were not affected by spacing pattern at either 0 kg N ha^{-1} or at 60 kg N ha^{-1}.

In 1986, total yields were not affected by spacing pattern or corn hybrid when tall corn and dwarf corn intercrops were contrasted in each other's regular spacing pattern (Table 5.6). Furthermore, no differences were found between spacing patterns or corn hybrids when soybean yields alone or corn yields alone were compared (data not shown). However, the dwarf corn intercrop (normally at S1) had a comparatively low LER of 1.03 at S3.

In the 1987 farm-scale experiment, corn yielded the most grain in the monocrop and more in the intercrop than in the strip-crop (Table 5.7). Soybean yields were highest in the monocrop and were higher in the strip-crop than in the intercrop. The total crop yield was similar in the corn monocrop and in the intercrop, both of which had higher total yields than the strip-crop. The intercrop LER was 1.17, within the range of the 1985 and 1986 tall corn intercropping results at 60 and 120 kg N ha^{-1} (Martin et al. 1990a). However, the strip-crop LER was 1.02, significantly lower than 1.17.

5.4. Discussion :

In 1985 a relatively dry year, the yield of monocropped nodulating soybean was 27% less than in 1986 and was at a level numerically less than that of monocropped nonnodulating soybean (Table 5.2). Intercropped nodulating soybean yields were reduced by 39% to 48% in

Table 5.6. Dry weight biomass yields (kg ha^{-1}) and LERs of intercropped nodulating Maple Arrow soybean and two corn hybrids at two spacing patterns at 60 kg N ha^{-1}, in 1986.

Total Corn and Soybean Yield and LER

Treatment	Spacing Pattern S1	Spacing Pattern S3	Corn Hybrid Main Effect
Dwarf-Nod N60	13272aA	12606aA	12939a
	[1.12]*	[1.03]	
Tall-Nod N60	12807aA	13213aA	13010a
	[1.14]	[1.13]	
(S Main Effect)	13040 A	12910 A	

* square brackets enclose LER values; S = Spacing pattern; S1 and S3 defined in Table 1; means in a column, followed by the same lower case letter or means in a row followed by the same upper case letter are not significantly different ($p < 0.05$, Protected LSD).

Table 5.7. Grain dry weight yields and LERs of corn and soybean, in 1987.

Treatment	Yield (kg ha^{-1})			LER
	Corn	Soybean	Total	
Monocrop Corn	5671a	---	5671a	--
Intercrop	4394b	901c	5295a	1.17a
Strip-crop	2977c	1131b	4108b	1.02b
Monocrop Soybean	---	2302a	2302c	--

Means in a column, followed by the same letter are not significantly different ($p < 0.05$, Protected LSD).

1985 compared to 1986 (Tables 5.3 and 5.4). These results contradict the observations of Allen and Obura (1983), who found both monocropped and intercropped nodulating soybean yields to be about the same, under moisture stress or when irrigated to field capacity. Smith and Hume (1985), found that soybean seed yields were higher in irrigated than in nonirrigated treatments in only the driest of three years and at the lowest soil N site. Irrigation improved soybean seed yields by 42% In our experiment, stress due to low moisture was compounded with low N stress when N applications were withheld. Nonnodulating soybean, when associated with nodulating soybean or dwarf corn at 0 kg N ha^{-1} in 1985, yielded very poorly in comparisons with nodulating soybean (Tables 5.2 and 5.3). Lack of moisture may have reduced the rate of N mineralization, nitrification and NO_3 mobility so that nodulating plants, with more extensive root systems competed more successfully than nonnodulating plants under intercropping conditions.

The low nonnodulating yield in 1985, in the soybean mixture, did not result in a crude protein concentration significantly higher than that of higher yielding monocropped nonnodulating soybeans. An inverse relationship between soybean yield and protein concentration has been previously reported (Salado-Navarro et al. 1985). The intense competition for moisture and soil N seemed to preclude compensatory nitrogen uptake by the lower yielding nonnodulating plants.

In 1986, the genotype yields were similar in the mixture of nodulating and nonnodulating soybean. The protein concentration was higher in the nonnodulating soybean in the mixture than in the monocropped nonnodulating soybean (Table 5.2). Interpretation is complicated by the fact that the soybean plants in the mixture were at a population density 33% higher than soybean plants under monocropping. However, the soybean mixture contained a total of 1056 kg protein ha^{-1}, almost double the production of 561 kg protein ha^{-1} by monocropped nonnodulating soybeans. Much of the extra protein yield can be attributed to nodule nitrogen fixation. Nitrogen may have been transferred from the nodulating to the nonnodulating soybeans (Burton et al. 1983). Vest (1971) also hypothesized that soil nitrogen might be spared by N_2 fixing nodulating soybeans for nonnodulating plants in a mixture. Vallis et al. (1967) found that lucerne spared soil nitrogen for grass plants. Danso et al. (1987) argued that soil N was not spared by fababeans for associated barley, since no more N was removed by barley in an intercrop than in a monocrop. An increased proportion of fababean total N was derived from N_2 fixation in an intercrop with barley, presumably to compensate for the low soil N levels resulting from the superior competitiveness of barley for soil N.

If the available soil N is indicated by the yield of 561 kg protein ha^{-1} by monocropped nonnodulating soybean and 100% of the protein in mixture nonnodulating soybean is derived from the soil then only 22% of the nodulating soybean protein was derived from the soil and 78% from fixed N_2. George et al. (1988) recorded a range of 62% to 98% of the total N derived from N_2 fixation in five soybean cultivars at three elevations. However, LaRue and Patterson (1981) have reviewed numerous experiments and concluded that unless soil N is low, N_2 fixation probably accounts for less than 50% of total N in soybean plants. On our experimental sites, in 1985 and 1986, monocropped corn yields did not respond to more than 60 kg N ha^{-1} (Martin et al. 1990a), an indication that soil N was not low. Talbott et al. (1985) found that nodulating and nonnodulating soybeans competed equally for soil N. If this held true in our experiment, then 56% of the protein in nodulating soybean was derived from N_2 fixation and 33% of the 418 kg protein ha^{-1} in nonnodulating soybean was transferred from associated nodulating soybean. Decomposed roots and root nodules of nodulating plants may have been the source of some transferred N (Vasilas and Ham, 1985).

In 1986, dwarf corn took up significantly more N when intercropped with nodulating soybean than when intercropped with nonnodulating soybean (Table 5.4). This concurs with observations of N transfer from soybean to sorghum (Elmore and Jackobs, 1986). If the N benefit was not due to N transfer it is still clear that the contribution of soybean nodule N_2 fixation was to increase total intercrop protein yields compared to intercrops with nonnodulating soybean at the same population density, spacing pattern and N fertilizer levels.

Nodulating soybeans can aggressively compete for soil N (Johnson et al. 1975). This was observed in the drier year of 1985, when protein yields of dwarf corn intercropped with nodulating soybeans were not higher than those of corn intercropped with nonnodulating soybean (data not shown). In fact, dwarf corn biomass yields were lower in association with the higher producing nodulating soybean than with the nonnodulating soybean (Table 5.3).

The higher crude protein concentration of Nattawa, compared to Maple Arrow (Table 5.2), may be attributable to the commonly observed inverse relationship between yield and crude protein concentration (Salado-Navarro et al. 1985). However, dwarf corn yields were not significantly improved in association with this lower yielding genotype (Table 5.3). Significant soybean genotype by cropping system interactions were reported when fifty soybean genotypes were grown in monocrops and intercrops with corn (Sharma and Mehta, 1988), suggesting that selection of soybean genotypes for high yield in intercrops should be conducted under intercropping rather than monocropping systems. In our experiments there was no interaction between the soybean genotypes, Maple Arrow and Nattawa, and the cropping systems, monocropping and intercropping. Maple Arrow could have been chosen as the best soybean cultivar for intercropping with corn under a monocropping system.

Intercrops of dwarf corn with nodulating or nonnodulating soybeans were not affected by spacing pattern (Table 5.3). It was expected that alternate rows of soybean and corn would lessen competition between corn (Dalal, 1977) and soybean (Fisher et al. 1987) thereby increasing total silage yield. Alternatively, dwarf corn intercropped with nodulating soybean, might have benefited from the closer association of corn and soybean roots in S1 (Van Kessel and Roskoski, 1988; Chui and Nadar, 1985). However, there was not an interaction between soybean genotype and spacing pattern; both nonnodulating and nodulating soybean tended to decrease dwarf corn yields at S2. Perhaps the soybean plants between dwarf corn rows reduced corn yields by excessive shading of the lower corn leaves.

In 1986, the S4 spacing pattern resulted in higher soybean yields than S3 (Table 5.5,) probably because of reduced competition and more available light to soybean in a row with an 80 cm space separating the next soybean row. Soybean yields were also higher in wide corn rows than in narrow corn rows, according to Chiu and Shibles (1984) and Mohta and De (1980). Tall corn yields were reduced at S4, probably because of greater intrarow competition between corn plants, the close proximity of soybean rows and the lack of a nitrogen application to reduce corn-soybean competition. However, competition was not reduced sufficiently by 60 kg N ha^{-1} to negate the corn yield difference between S4 and S3.

At 0 kg N ha^{-1}, the soybean yield was numerically higher at P2 than at P1 and consequently LERs were slightly higher at P2 for each spacing pattern level (Table 5.5). Anwarhan (1984), found higher corn and soybean intercrop yields, LERs, gross returns and net returns with both crops at low population densities (40,000 corn and 200,000 soybean plants ha^{-1}) than with either crop or both crops at high population densities (60,000 corn and 400,000 soybean plants ha^{-1}). Yunusa (1989), showed that a corn-soybean intercrop with each component crop at 67% of it's monocrop population, produced more than corn-soybean combinations of 100%:100%, 67%:33% or 33%:67%, respectively. In 1986, at 60 kg N ha^{-1}, we found that when intercropped corn was at 100% and intercropped soybean at either 50% or 100% of their respective monocrop populations (Martin et al. 1990a) total intercrop yields, LERs and cost efficiency was higher than at P1 or P2. Putnam et al. (1985) observed a linear increase of total intercropped yields with increasing densities of the corn component.

Total intercrop yields indicated that dwarf corn tolerated intrarow corn-corn competition (S3) as well as corn-soybean competition (S1) (Table 5.6). An anticipated interaction, in which each hybrid performed best in it's normal pattern, was not detected. However, the 1.03 LER of dwarf corn - nodulating soybean at S3 was 0.09 less than at S1 and 0.10 less than tall corn - nodulating soybean at S3, indicating a noticeable decrease of land use efficiency by increasing the intrarow competition of dwarf corn. This LER comparison, although non-rigorous, was meaningful because the management level was the same for monocrops and intercrops (Willey, 1979) of corn.

LER comparisons of nonlegumes or nonnodulating legumes in monocrops and intercrops at unmatched management levels of N, in particular, must be considered cautiously. An unmatched low monocrop denominator of L_a or L_b artificially inflates the ratios. The 1.45 protein LER of dwarf corn and nonnodulating soybean (Table 5.4) is an example. Monocropped nodulating legumes with no applied N can be usefully compared to an intercrop with applied N since N applications do not increase yields of the legume monocrop.

In 1987, the stripcrop spacing pattern was not more efficient than monocrops of corn and soybean (Table 5.7), and the LER (1.02) was similar to the LERs calculated from the results of Pendleton et al. (1963). Intraspecific competition of stripcropped corn at 72% of the monocrop population in the entire cropping area or at 144% of the monocrop population per unit area allocated to corn, was apparently too extreme. In 1986, intercropped corn yielded very well at 100% of the monocrop population (Martin et al. 1990a) but it was not restricted to half the land surface area as was the case in the 1987 stripcrop. The low yields of stripcropped corn, paralleled low corn yields in the restricted area of the S4 spacing pattern, in 1986. In both 1986 and 1987, corn yields and LERs were higher in associated corn and soybean cropping systems, when soybean was planted within or between corn row widths equidistantly spaced rather than between displaced corn rows which provided extra space for soybean. The objective of the farm-scale experiment was to harvest more grain from each of the corn and soybean crops grown in association (intercrops and stripcrops) rather than in separate monocrops. It appears that grain yields have similar advantages to forage yields in intercrops but present harvesting equipment does not permit separation of corn kernels and soybean seeds from an intercrop. Stripcrops would accommodate separate harvesting of corn and soybean but the results here and by Pendleton et al. (1963) show no yield advantage compared to separate monocrops.

In summary, soybean nodulation increased the competitiveness of soybeans in a drier year, to the detriment of the associated crop. When moisture was not limiting, nonnodulating soybean and dwarf corn derived N and yield benefits from the nodulating soybean. The contrast between within-row and between-row spacing patterns had no effect on intercrop yields of soybean and corn. Corn-soybean intercrops were more productive when all corn row widths were equidistantly spaced.

Preface to Section 6

Section 6 is part of the manuscript by Martin et al. (1990c) submitted to the journal, Plant and Soil, and part of the manuscript by Martin et al. (1990d) submitted to the journal, The New Phytologist. The format has been changed to conform as much as possible to a consistent format within this thesis. All literature cited in this section is listed in the reference section at the end of the thesis. Each table is presented on the page following the first referral to it.

Agronomic and economic advantages of corn-soybean intercropping were demonstrated in section 3 and the improved yield and protein levels of corn or nonnodulating soybean in association with nodulating soybean were demonstrated in section 5. Section 6 addresses a potential mechanism of intercropping advantage when a non-N_2 fixing crop is associated with an N_2-fixing crop. Nitrogen transfer from nodulating soybean to corn and to nonnodulating soybean is examined in this section.

Section 6

NITROGEN TRANSFER IN INTERCROPS FROM NODULATING SOYBEAN TO CORN AND TO NONNODULATING SOYBEAN IN A COOL TEMPERATE REGION

6.0. Abstract :

In 1985 and 1986, corn was monocropped and intercropped with nodulating and nonnodulating soybean at 0 and 60 kg N ha^{-1}. In 1988, intercrops of corn - nodulating soybean, corn - nonnodulating soybean and nodulating soybean - nonnodulating soybean as well as monocrops of each crop were grown on soil depleted of N and on non-N-depleted soil. ^{15}N enriched N was applied to soil in all the aforementioned treatments to test N transfer by the ^{15}N dilution method. In 1988, enriched N was also directly applied to a petiole or to secondary roots of nodulating soybean to test N transfer to corn and to nonnodulating soybean.

The ^{15}N dilution method did not show the occurrence of N transfer in 1985 and 1986 but the N-sparing effect was evident from the total N uptake of nonnodulating soybean, dwarf corn and tall corn, in 1986. In 1988, corn grain and nonnodulating soybean seed yields and N yields were higher on non-N-depleted soil compared to N-depleted soil but nodulating soybean responded inversely to the non-N_2 fixing crops. On N-depleted soil, the ^{15}N dilution method indicated N transfer from nodulating soybean to corn and to nonnodulating soybean. At a population ratio of 66% nodulating soybean to 33% nonnodulating soybean, N transfer was also seen on non-N-depleted soil in 1988.

In the field in 1988, enriched N applied directly to a petiole of

nodulating soybean was detected at significantly higher levels in adjacent corn plants than when unenriched N was similarly applied. Applications of enriched N and unenriched N to nodulating soybean roots did not result in significant differences of % ^{15}N in adjacent corn plants. However, in pots in a greenhouse, enriched N applied to secondary roots of nodulating soybean in split-root systems, was detected at higher levels in associated corn and nonnodulating soybean than when unenriched N was similarly applied.

6.1. Introduction :

Corn (Zea mays L.) and soybean (Glycine max [L.] Merr.) intercrops frequently have advantageous Land Equivalent Ratios (LERs) (Putnam et al. 1986; Yunasa, 1989 and Martin et al. 1990a and others). However, in a survey of a broad range of intercrops, evaluations with Area-x-Time Equivalency Ratios (ATERs) (Hiebsch and McCollum, 1987), showed that many LER advantages were attributable to the prolonged exposure to light of at least one of the component crops before or after the intercropping period. The exceptions were legume-nonlegume intercrops which consistently had advantageous ATERs as well as LERs. N_2 fixation by legumes was credited for this consistent advantage. The contribution of N_2 fixation in soybean was also apparent in the high protein concentrations of 10.2 to 10.8% in corn-soybean silage. These values were higher than in corn silage (Herbert et al. 1985; Putnam et al. 1986; Toniolo et al. 1987; and Martin et al. 1990a).

Corn had higher protein and yield levels when grown in association with nodulating soybean than when grown with nonnodulating soybean and the nonnodulating soybean protein concentration was higher when grown in a mixture with nodulating soybean than in a nonnodulating monocrop (Martin et al. 1990b). Elmore and Jackobs (1986) also measured higher sorghum N yields in sorghum grown with nodulating soybean than in sorghum grown with nonnodulating soybean. They attributed the difference to transfer of nitrogen from nodulated soybean.

Eaglesham et al. (1981) reported a higher N content and a significant dilution of ^{15}N in maize intercropped with cowpea compared to monocropped maize. It was assumed that the extra nitrogen in intercropped maize was transferred from the cowpea. They concluded that nitrogen excretion by an intercropped legume gives significant benefit to the associated crop only in conditions of low soil mineral N status. Patra et al. (1986) found that cowpea contributed 16 to 32% of the total N uptake of intercropped maize in greenhouse trials and cowpea contributed 28% or 21.2 kg N ha^{-1} in field trials. In a split root experiment, van Kessel et al. (1985), showed that ^{15}N added to a partial soybean root system in one pot could be detected in a corn shoot in an adjacent pot with the other part of the soybean root system. However, van Kessel and Roskoski (1988) were unable to detect nitrogen transfer from cowpea to maize in a field trial when using the ^{15}N dilution method.

Most experiments assessing N transfer from seed legumes to corn have been conducted in warm low-latitude regions with long growing seasons. The objective of this study was to test nitrogen transfer in field experiments from soybean to corn within a relatively short and cool growing season at Ottawa, Ontario, at 45° N latitude. A further objective was to compare nitrogen transfer on a field site with treatments of N-depleted and non-N-depleted soil N.

6.2. Materials and methods :

The study was conducted at the Central Experimental Farm of Agriculture Canada in Ottawa, Ontario from 1985 to 1988. Unless otherwise specified the materials used and the methods followed were the same as reported by Martin et al. (1990b).

The nitrogen transfer hypothesis was tested by the ^{15}N dilution method (Eaglesham et al. 1981) in assigned ^{15}N subplots in 1985, 1986 and 1988. $^{15}NH_4{}^{15}NO_3$ was dissolved in water at appropriate concentrations for each year and then sprinkled within ^{15}N subplot boundaries which were diked to prevent flow outside the boundaries. A thin layer of loose soil was spread over the subplot to decrease volatilization of ammonia. Nitrogen applied in this manner was in addition to treatment applications of 0 or 60 kg N ha^{-1}. In all cases, the longest dimension of the subplot was parallel to the length of the row with the subplot centred over one or two rows in the centre of the plot.

The procedure used for ^{15}N analysis was an adaptation of the Dumas method (Preston et al. 1981, Fiedler and Proksch, 1975). An aliquot, containing 7 μg of N, was taken from a Kjeldahl distillation solution and added to a 6 mm glass tube and dried. When the distillation solution had not been retained, plant samples were digested again in the first step of the Kjeldahl process and diluted in water to accurately obtain a solution volume containing 7 μg of N. After most of the water had been allowed to evaporate from the sample in a dessicator, the strongly acidic ($pH < 0.05$) remaining solution was dried at 400°C. Previously heated CuO (catalyst) and CaO (drying agent) were then added, in excess, to each tube and each tube was attached to a vacuum line and evacuated to a pressure of < 0.006 mbar. The tubes were then sealed by closing them at about 12 cm from the bottom with an acetylene torch. The sealed tubes were baked overnight at 500°C before being analyzed for % ^{15}N on an emission spectrometer.

Biomass yields and crude protein concentrations and amounts were analysed by analysis of variance (SAS Institute Inc., 1982). The percent ^{15}N values were analyzed to determine differences between treatments after an arcsine transformation of the data but the untransformed data are presented in the tables. The significance ($P \leq 0.05$) of the main effect of each factor and all possible interactions were considered. When significant differences were found, a protected LSD test for a range of more than two means or an orthogonal contrast for two means was applied (Steel and Torrie, 1980).

6.2.1. 1985 and 1986 ^{15}N dilution experiments :

On June 26, 1985, 10 kg ^{15}N ha^{-1} or 28.6 kg of $^{15}NH_4{}^{15}NO_3$ ha^{-1} (13.5% atom excess) was applied to a 1 m x 0.5 m subplot within each of nine treatments, in each of four replicates. The subplots were centred over two rows. The treatments included two dwarf corn monocrops at 0 and 60 kg N ha^{-1}, one monocrop of nodulating soybean and one monocrop of nonnodulating soybean, each at 0 kg N ha^{-1}. Each soybean monocrop was at a population density of 100% (500,000 plants ha^{-1}) and corn monocrops were at population densities of 100% (60,000 plants ha^{-1}) Dwarf corn was also intercropped at the S1 spacing pattern (Table 6 1) with nodulating and nonnodulating soybean, each at 0 and 60 kg N ha^{-1}.

Table 6.1. Spacing pattern definitions.

Designation	Definition
S1	corn and soybean within the same rows, 40 cm apart.
S3	corn and soybean in alternate rows, 40 cm apart.
S4	corn in paired rows, 40 cm apart; soybean in two rows, each 20 cm outside a corn row; space of 80 cm between each four row combination.
S5	corn and soybean within the same rows, 80 cm apart.

The intercrops had the P1 population density of 67% of monocropped corn and 67% of monocropped soybean. A 67% - 67% mixture of the two soybean genotypes was also grown at 0 kg N ha^{-1}.

On July 4, 1986, 5 kg ^{15}N ha^{-1} or 14.8 kg of $^{15}NH_4{}^{15}NO_3$ ha^{-1} (15.0% atom excess) was applied to a 0.48 m^2 subplot within each of fourteen treatments, in each of four replicates. The lower concentration of ^{15}N in 1986 than in 1985 was found to be detectable in barley and soybean in corollory experiments by Dr. Caroline Preston at Agriculture Canada in 1985. Nine treatments were the same as those in 1985. In addition, tall corn was monocroppped and intercropped with soybean, both at 0 kg N ha^{-1}. The tall corn intercrops were either at the P1 population density (67% - 67%) or at the P2 population density (50% - 50%). Each of these population density levels was arranged in both the S3 and S4 spacing patterns (Table 6.1). In most treatments, plants could be sampled from a single row and the subplots were 0.4 m x 1.2 m. However, S3 treatments required samples from two adjacent rows to obtain both corn and soybean tissue and therefore these subplots were 0.6 m x 0.8 m. The 0.4 m x 1.2 m subplot dimensions were maintained for S4 treatments with 20 cm between corn and soybean rows.

6.2.2. 1988 ^{15}N dilution experiment :

The preparatory treatments were conducted from 1985 to 1987 inclusive, at the Central Experimental Farm of Agriculture Canada, on a Mountain sandy loam (Typic Haplaquod). The site was about 0.5 km west of the 1986 site.

In 1985, the site was divided into four replicates, each arranged in three parallel ranges of seven 4.8 m x 6 m plots to most efficiently utilize the land area available for a four year period. Eleven plots of each replicate were planted in 40 cm rows with Co-op S259 corn at 120,000 plants ha^{-1} and the remaining ten plots of each replicate were planted with nodulating Maple Arrow soybeans at 500,000 plants ha^{-1}. The two treatments were randomly assigned and intended to deplete soil N (corn) or to maintain soil N (soybean). Fertilizer was not applied but inoculant was applied to soybean. The treatments were repeated in 1986 and 1987 on exactly the same plot locations. In October of 1985, 1986 and 1987 all plant material was removed from the site.

In 1988, there was a random assignment of treatments to N-depleted soil plots in each replicate. The same treatments were also randomly assigned to non-N-depleted soil plots in each replicate. The tall corn hybrid, Co-op S259, was used exclusively in 1988 because it assimilated a higher protein concentration in 1985 and 1986 and a higher protein yield in 1986 than dwarf corn (Martin et al. 1990a). It was assumed that % ^{15}N could be more easily detected in a hybrid with a greater capacity for N uptake. Soybean and corn monocrops were planted in six, 80 cm rows and all intercrops were arranged in the S5 spacing pattern (Table 6.1).

Nodulating and nonnodulating soybean monocrops were at population densities of 100% (500,000 plants ha^{-1}) and corn monocrops were at population densities of 100% (60,000 plants ha^{-1}), 67% or 33%. There were two intercrop populations, 33% crop a - 67% crop b and 67% crop a - 33% crop b, for each intercrop of corn and nodulating soybean, corn and nonnodulating soybean and the mixture of nodulating and nonnodulating soybean. Since there were only ten non-N-depleted plots in each replicate, the monocropped corn at a population density of 33%

was not included on this soil. This treatment was deleted because it was not an intercrop and it was the least like normal agricultural practice.

The site was planted on May 12, 1988. Inoculant and 50 kg ha^{-1} of P_2O_5 and K_2O were added as 250 kg ha^{-1} of 0-20-20 with the planter. Nitrogen fertilizer was not applied except for ^{15}N.

On May 30 and 31, 1 kg ^{15}N ha^{-1} or 2.8 kg of $^{15}NH_4{}^{15}NO_3$ ha^{-1} (99% atom excess) was applied to 0.75 m x 0.75 m subplots, centred on the fourth row within the main 1.6 m x 2.5 m harvestable area in every treatment. The ^{15}N was applied in solution, within soil dike boundaries and covered with soil immediately. These subplots were harvested at the same time as the main harvestable area, September 13 to 16, 1988. The plants from the subplots were then oven-dried, weighed and threshed. The dry seeds were weighed and ground for Kjeldahl and ^{15}N analysis. Differences between treatments of % ^{15}N were expected to be more easily detected in the seeds because 90% of nitrogen is concentrated in nodulating soybean seeds (Smith et al. 1988), 82% of N is concentrated in nonnodulating soybean seeds (Talbott et al. 1985) and 70% of N is concentrated in corn kernels (Goodroad and Jellum, 1988). Dry weight yields ha^{-1} were calculated from all plants in the main harvestable area.

6.2.3. 1988 ^{15}N direct application field experiment :

The 99% ^{15}N enriched and unenriched urea was applied to roots and petioles on June 27 and repeated on July 7. The procedure was done in replicates 2, 3 and 4 of the treatment of 66% corn and 33% nodulating soybean on N-depleted soil. Eight positions around the main harvestable area, four in the second row, two in the fourth row and two in the fifth row were chosen. Each position was at least 1.1 m apart and at least 1.25 m from the subplot where ^{15}N was applied for the dilution method. The treatments for direct application of ^{15}N were randomly assigned to the eight positions. In four treatments, 100 mg of ^{15}N plant^{-1} or 218 mg of $H_2{}^{15}NCO^{15}NH_2$ plant^{-1} (99% atom excess) was applied. These applications were to the secondary roots of a soybean root system and to a petiole of another soybean plant on each date. The solution concentration was 6% urea, which was found to be an acceptable level for soybean petiole uptake in preliminary greenhouse trials. The same concentrations and amounts of unenriched urea were similarily applied to the soybean secondary roots of a soybean root system and to a petiole of another soybean plant on each date as well. Soybean and adjacent corn plants were harvested one week after each urea application. The whole plants were then oven-dried, weighed and ground for Kjeldahl and ^{15}N analysis.

Soybean plants for the split-root technique were planted in a growth chamber on May 25. The growth chamber was on a 16/8 hr day/night cycle. The day temperature was 28° C and the night temperature was 22° C. Light was provided mostly by fluorescent lights with supplementary incandescent bulbs. On June 6, the plants were taken to the field, removed from pots and their roots cleared of potting mixture. Half of each root system (excluding the primary tap root) was pulled through a 12 mm plastic elbow and placed in a 1 L. plastic container with field soil from the position of placement. The remaining half of each root system was placed in the assigned position in the field beside a corn plant, the container dug into the soil as well. Soil inside and outside the container was watered and the container was sealed and positioned at an angle with the lip above the ground to prevent soil water from entering through the elbow. The soil inside the container was kept moist until the date of urea application by pouring water through an extended 12 mm pipe which was otherwise capped. The urea was also added into the container, in solution, through the extended 12 mm pipe.

Soybean plants for petiole absorption of ^{15}N were field grown and selected according to the design above and for their proximity to a corn plant. The trifoliolate at the fourth or fifth node was cut off and the remaining petiole was immersed in a urea solution in a vial secured to a stake. The vial was tightly covered. After one or two days the petiole of an adjacent soybean plant was immersed as well if the solution was not absorbed. These plants were also harvested one week after ^{15}N application and analyzed.

6.2.4. 1988 ^{15}N direct application greenhouse experiment :

A corollary ^{15}N split-root experiment was conducted in the greenhouse. Corn and nodulating or nonnodulating soybean seeds were planted into vermiculite in a flat on June 17, 1988, and incubated in a growth chamber, under the same conditions described previously, until June 29. Soybean seeds were inoculated with <u>Bradyrhizobium japonicum</u> (Nitragin Co.). One corn seedling and one nodulating soybean seedling were transplanted to each of nine 13 cm pots in a greenhouse on June 29. A soybean split-root system was set up such that half the roots of each nodulating soybean (excluding the primary tap root) were pulled through a 12 mm plastic elbow and placed into an adjacent 10 cm pot. A soil mixture was three parts loam soil, two parts ASB commercial peat moss, 1.5 parts Turface (Plant Products Co.) and one l of pulverized limestone in each m^3 of mixture. The pots were well-watered and the soybean seedlings inoculated again with _B. japonicum_. Similarily, nine split-root systems were set up on July 6 with nodulating soybean associated with nonnodulating soybean rather than corn.

Pots placed on saucers were bottom watered as required. On July 19 the water in the saucers of 13 cm pots was replaced by a nutrient solution of 10-52-10 fertilizer diluted to 7.5 ml in one L of water.

On July 25, 107 mg of ^{15}N plant^{-1} or 233 mg of $H_2{}^{15}NCO{}^{15}NH_2$ plant^{-1} (99% atom excess) was applied in solution to every third 10 cm pot containing part of a nodulating soybean root. The solution was pipetted into a depression in the soil at the top of the pot and immediately covered with two cm of soil from the pot. The second treatment was the same except that ^{15}N enriched material was replaced by unenriched material and the third treatment was a control with water but no N added. All plants were harvested on July 29 and then oven-dried, weighed and ground for Kjeldahl and ^{15}N analysis.

6.3. Results :

In 1985, the corn biomass and nitrogen yields were higher (usually significantly) at 60 kg N ha^{-1} than at 0 kg N ha^{-1} (Table 6.2). Corn yields at 60 kg N ha^{-1} were higher in association with the nonnodulating than with the nodulating soybean. In association with corn, nodulating soybean yields were higher than nonnodulating soybean yields.

Table 6.2. Dry weight yield of plant biomass (kg ha^{-1}) and plant nitrogen (g m^{-2}) of dwarf corn and nodulating and nonnodulating soybean in monocrops and intercrops in 1985.

Treatment		Crop a		Crop b		Total	
Crop		biomass	N	biomass	N	biomass	N
a	b						
Dwarf	0N	9127bc	9.2bc	-	-	9127bc	9.2b
Dwarf	60N	11450a	11.9a	-	-	11450a	11.9a
Dwarf-Nod	0N	5506d	4.9d	1502a	3.7a	7008c	8.7b
Dwarf-Nod	60N	7272cd	8.2c	1461a	3.7a	8733bc	12.0a
Dwarf-NN	0N	6406d	7.0cd	782b	1.3b	7188c	8.2b
Dwarf-NN	60N	9508ab	10.9ab	983b	1.9b	10491ab	12.8a
Nod	0N	4045a	9.8a	-	-	4045a	9.8a
NN	0N	-	-	4170a	8.2a	4170a	8.2a
Nod-NN	0N	2702bA	7.8bY	989bB	2.1bZ	3690a	9.9a

Nod = nodulating soybean; NN = nonnodulating soybean; 0N and 60N = 0 and 60 kg N ha^{-1}, respectively; Means in a column, followed by the same lower case letter or means in a row followed by the same upper case letter are not significantly different ($p < 0.05$, Protected LSD).

The % ^{15}N of dwarf corn intercropped with nodulating soybean was not significantly lower than the %^{15}N in dwarf corn monocropped or intercropped with nonnodulating soybean at the same N level (Table 6.3). Nodulating soybean took up more $^{15}N\ m^{-2}$ than nonnodulating soybean and averaged over the 0 and 60 kg ha^{-1} N levels, the % ^{15}N was significantly lower in nodulating soybean. Averaged over the three cropping systems containing dwarf corn, the amount of $^{15}N\ m^{-2}$ taken up by dwarf corn was less at 0 than at 60 kg N ha^{-1}. The %^{15}N enrichment in dwarf corn was higher at 0 than at 60 kg N ha^{-1} averaged over the same cropping systems.

In 1986, a year of more rainfall than in 1985, biomass and nitrogen yields of dwarf corn at 60 kg N ha^{-1} were higher in association with nodulating soybean than when intercropped with nonnodulating soybean (Table 6.4). Total yields for cropping systems containing dwarf corn were higher at 60 kg N ha^{-1} than at 0 kg N ha^{-1}. Tall corn nitrogen yields were not affected by spacing pattern or population density, but all total nitrogen yields of tall corn-soybean intercrops were higher than that of monocropped tall corn.

In 1986, dwarf corn intercropped with nodulating soybean was as enriched with % ^{15}N as dwarf corn monocropped or intercropped with nonnodulating soybean, at the same N level (Table 6.5). In dwarf corn - soybean intercrops, at both 0 and 60 kg N ha^{-1}, nodulating soybean had a lower % ^{15}N than nonnodulating soybean. Averaged over all dwarf corn cropping systems, the %^{15}N enrichment in dwarf corn was higher at 0 than at 60 kg N ha^{-1}. The amount of $^{15}N\ m^{-2}$ taken up in dwarf corn was less at 0 than at 60 kg N ha^{-1} averaged over all dwarf corn cropping systems. There was a significant interaction between cropping

Table 6.3. Concentration (%) and amount (mg m^{-2}) of ^{15}N in plants of dwarf corn and nodulating and nonnodulating soybean in monocrops and intercrops in 1985.

Treatment		%^{15}N	mg^{15}N	%^{15}N	mg^{15}N	mg^{15}N
		corn		soybean		total
Dwarf	0N	1.0615a	95.8abc	-	-	95.8a
Dwarf	60N	0.8634b	102.6a	-	-	102.6a
Dwarf-Nod	0N	1.1049a	53.4d	0.7713a	28.9a	82.3a
Dwarf-Nod	60N	0.9047b	74.1cd	0.8075a	30.4a	104.4a
Dwarf-NN	0N	1.1214a	77.9bc	1.0606a^{M}	12.2b^{M}	93.8a
Dwarf-NN	60N	0.9002b	98.1ab	0.8669a	16.6b	114.6a
N effects averaged over three dwarf corn cropping systems						
	0N	1.0960a	75.7b	0.8953a	21.7a	90.4a
	60N	0.8895b	91.6a	0.8373a	23.5a	107.2a

Nod = nodulating soybean; NN = nonnodulating soybean; 0N and 60N = 0 and 60 kg N ha^{-1}, respectively; ^{M} Missing value for one replicate; Means in a column, followed by the same letter are not significantly different ($p < 0.05$, Protected LSD).

Table 6.4. Dry weight yield of plant biomass (kg ha^{-1}) and plant nitrogen (g m^{-2}) of dwarf corn and tall corn and nodulating and nonnodulating soybean in monocrops and intercrops in 1986.

Treatment		Crop a		Crop b		Total	
Crop		biomass	N	biomass	N	biomass	N
a	b						
Dwarf	0N	10995b	10.7bc	-	-	10995b	10.7c
Dwarf	60N	14684a	17.1a	-	-	14684a	17.1ab
Dwarf-Nod	0N	7319c	7.9de	2874a	7.9a	10193bc	15.8b
Dwarf-Nod	60N	10775b	12.6b	2496ab	6.5a	13271a	19.1a
Dwarf-NN	0N	6856c	6.7e	1927b	2.7b	8783c	9.4c
Dwarf-NN	60N	8289c	9.2cd	3285a	5.8a	11575b	15.0b
Tall	0N	10423a	11.2a	-	-	10423a	11.2b
Tall-Nod	0N S3 P1	8691ab	9.7a	2483c	6.2c	11174a	15.9a
Tall-Nod	0N S3 P2	8021b	10.2a	3088bc	8.1bc	11109a	18.4a
Tall-Nod	0N S4 P1	5979c	7.3a	3319ab	10.4ab	9765a	19.0a
Tall-Nod	0N S4 P2	6181c	7.8a	3721a	11.1a	9902a	18.9a
Nod	0N	6447a	19.0a	-	-	6447a	19.0a
NN	0N	-	-	5816a	9.0a	5816a	9.0b
Nod-NN	0N	3178bA	10.2bY	3559bA	6.7bY	6736a	16.9a

Nod = nodulating soybean; NN = nonnodulating soybean; 0N and 60N = 0 and 60 kg N ha^{-1}, respectively; S3 and S4 defined in Table 1; P1 = 67% crop a - 67% crop b; P2 = 50% crop a - 50% crop b; Means in a column, followed by the same lower case letter or means in a row followed by the same upper case letter are not significantly different ($p < 0.05$, Protected LSD).

Table 6.5. Concentration (%) and amount (mg m^{-2}) of ^{15}N in plants of dwarf corn and tall corn and nodulating and nonnodulating soybean in monocrops and intercrops in 1986.

Treatment	$\%^{15}N$	$mg^{15}N$	$\%^{15}N$	$mg^{15}N$	$mg^{15}N$
	corn		soybean		total
Dwarf ON	0.7389ab	79.0b	-	-	79.0b
Dwarf 60N	0.6890bc	118.0a	-	-	118.0a
Dwarf-Nod ON	0.7759a	61.5c	0.5034b	39.9a	101.4a
Dwarf-Nod 60N	0.6372c	79.6b	0.5258b	34.0a	113.6a
Dwarf-NN ON	0.7837a	51.7c	0.7380a	19.6a	71.3b
Dwarf-NN 60N	0.6412c	58.8c	0.7567a	45.9a	104.7a
N effects averaged over three dwarf corn cropping systems					
ON	0.7662a	64.1x	0.6208a	29.8a	83.9b
60N	0.6558b	85.5x	0.6413a	40.0a	112.2a
Tall ON	0.5694b	62.9a	-	-	62.9b
Tall-Nod ON S3 P1	0.6556a	63.4a	0.5661a	34.8b	98.2a
Tall-Nod ON S3 P2	0.6279ab	62.8a	0.5929a	48.5ab	111.3a
Tall-Nod ON S4 P1	0.6604a	50.6a^{M}	0.5641a	59.2a^{M}	117.5a
Tall-Nod ON S4 P2	0.5632b	43.5a	0.5140b	57.3a	100.9a

Nod = nodulating soybean; NN = nonnodulating soybean; ON and 60N = 0 and 60 kg N ha^{-1}, respectively; S3 and S4 defined in Table 1; P1 = 67% crop a - 67% crop b; P2 = 50% crop a - 50% crop b; x = significant interaction ($p < 0.05$) of the main effects; ^{M} Missing value for one replicate; Means in a column, followed by the same letter are not significantly different ($p < 0.05$, Protected LSD).

system and N level as the difference between N levels was smaller in the cropping system of dwarf corn - nonnodualting soybean than in dwarf corn - nodulating soybean or monocropped corn. Averaged over the three dwarf corn cropping systems, the total crop uptake of ^{15}N m^{-2} was higher at 60 than at 0 kg N ha^{-1}.

In 1986, the tall corn in both P1 intercrops had % ^{15}N levels that were unexpectedly higher than that of the tall corn monocrop (Table 6.5). The amounts of ^{15}N m^{-2} were not different in corn and ^{15}N m^{-2} tended to be higher in soybean under S4 than S3. Each tall corn intercrop accumulated more ^{15}N m^{-2} in the total yield than monocropped tall corn.

In 1985 and 1986, monocropped soybean yields were greater than yields of either nodulating or nonnodulating soybean as component crops in a mixture of the two soybean genotypes (Tables 6.2 and 6.4). In 1985, nodulating soybean yielded about three times higher than nonnodulating soybean when the genotypes were competing in a mixture (Table 6.2). In 1986, the nonnodulating soybean monocrop took up about half the N in the nodulating monocrop or the soybean mixture (Table 6.4).

In 1985 and 1986, the % ^{15}N of nonnodulating soybean associated with nodulating soybean was not significantly less than monocropped nonnodulating soybean, but there was such a trend in 1986 (Table 6.6). The nodulating soybean monocrop had a lower level of %^{15}N enrichment than the nonnodulating soybean monocrop, indicating a reliance on N_2 fixation for part of its total N. Within the soybean mixture, the % ^{15}N of nodulating soybean was also lower than that of nonnodulating soybean in both years.

Table 6.6. Concentration (%) and amount (mg m^{-2}) of ^{15}N in plants of nodulating and nonnodulating soybean in monocrops and in a mixture in 1985 and 1986.

	1985		1986	
Treatment	%^{15}N	mg^{15}N	%^{15}N	mg^{15}N
Nod	b0.9329b	a91.0a	b0.5959b	a112.5a
NN	a1.2683a	a104.4a	a0.7556a	b66.3b
Nod (with NN)	0.9638b	74.5a	0.5608b	57.0b
NN (with Nod)	1.2856a^{M}	25.3b^{M}	0.7092a	46.9b
Nod-NN (total)	b1.0219	a102.5	b0.6261	a103.9

Nod = nodulating soybean; NN = nonnodulating soybean; ^{M} Missing value for one replicate; Means in a column, followed by or preceded by the same letter are not significantly different ($p < 0.05$, Protected LSD).

In 1988, the total N accumulation averaged 3.9 g N m^{-2} (excluding treatments with nodulating soybean and monocropped corn at less than 100% population density) on N-depleted soil N plots, compared to 6.6 g N m^{-2}, in the same treatments on non-N-depleted plots (Table 6.7). Averaged over all treatments, the biomass yields and nitrogen taken up by nonnodulating soybean seeds were also lower on N-depleted than on non-N-depleted soil N plots (Table 6.7), a clear indication that soil N was in fact depleted. Conversely, the yields and nitrogen for nodulating soybean seeds were higher, averaged over all treatments, on N-depleted soil than on non-N-depleted soil, an indication that nodulating soybean fixed more N_2 on the N-depleted plots.

There was an interaction between soil N level and population treatments for corn grain biomass and N yield, although values on non-N-depleted soil were consistently higher than on N-depleted soil (Table 6.7). Orthogonal contrasts between the two soil N depletion levels revealed significantly lower biomass yields on N-depleted soils for the population treatments, 66% corn - 33% nodulating soybean, 66% corn - 33% nonnodulating soybean and in 100% monocropped corn. Orthogonal contrasts also showed that N yields in corn grain was significantly lower on N-depleted soils in all population treatments, except the 33% corn - 66% nodulating soybean combination.

Biomass and nitrogen yields were higher in seeds of monocropped nodulating and nonnodulating soybean, and corn grain than in the respective component crops in intercrops (Table 6.7). As expected, values were lower in component crops as the proportion of that crop decreased relative to that of the other component crop. Both nodulating and nonnodulating soybean component crops showed trends,

Table 6.7. Dry weight yield of biomass (kg ha^{-1}) and nitrogen (g m^{-2}) in corn grain, and nodulating and nonnodulating soybean seeds in monocrops and intercrops in 1988.

Treatment	Corn		Nod		NN		Total	
D0	biomass	N	biomass	N	biomass	N	biomass	N
100Nod	-	-	1583.2a	10.4a	-	-	1583.2d	10.4a
100NN	-	-	-	-	1285.3a	6.2a	1285.3d	6.2cd
33C-66Nod	1609.5c	2.7c	850.4c	5.7c	-	-	2459.9c	8.4b
33C-66NN	1824.6c	3.0c	-	-	561.9b	2.7b	2386.4c	5.7d
33Nod-66NN	-	-	806.7c	5.1c	625.6b	3.2b	1432.2d	8.3b
66C-33Nod	3958.8b	5.7b	343.0d	2.3d	-	-	4301.8b	8.0b
66C-33NN	3930.0b	5.6b	-	-	274.3c	1.4c	4204.3b	7.0bcd
66Nod-33NN	-	-	1264.3b	8.3b	316.4c	1.7c	1580.6d	10.0a
100C	5341.0a	7.4a	-	-	-	-	5341.0a	7.4bc
66C	3798.7b	6.2ab	-	-	-	-	3798.7b	6.2cd
D1								
100Nod	-	-	1932.5a	12.6a	-	-	1932.5f	12.6a
100NN	-	-	-	-	1005.6a	4.2a	1005.6g	4.2d
33C-66Nod	1258.2d	1.8c	1206.0c	7.9bc	-	-	2464.2de	9.7b
33C-66NN	1452.7d	1.9c	-	-	319.4bc	1.3c	1771.8f	3.2d
33Nod-66NN	-	-	1050.4c	6.5c	506.7b	2.3b	1557.1f	8 8b
66C-33Nod	2631.6b	3.0b	640.7d	4.1d	-	-	3272.3bc	7.1c
66C-33NN	2756.6b	3.1b	-	-	130.0c	0.5c	2886.6cd	3.6d
66Nod-33NN	-	-	1450.7b	9.5b	182.4c	0.9c	1633.1f	10.3b
100C	4151.0a	4.7a	-	-	-	-	4151.0a	4.7d
66C	3789.1a	4.8a	-	-	-	-	3789.1ab	4.8d
33C	2058.5c	3.4b	-	-	-	-	2058.5ef	3.4d

Table 7 continued

Depletion effects averaged over all^z treatments								
D0	3410.5x	5.1x	969.5b	6.3b	612.7a	3.0a	2837.4x	7.8x
D1	2673.2x	3.2x	1256.1a	8.1a	428.8b	1.8b	2446.4x	6.9x

Table 6.7 legend.

C = corn; Nod = nodulating soybean; NN = nonnodulating soybean; Crops preceded by 33, 66 and 100 = 33%, 66% and 100% of respective monocrop populations; D0 = non-N-depleted soil; D1 = N-depleted soil; ^{z} Excluding 33C; x = significant interaction ($p < 0.05$) of the main effects; Means in a column, followed by the same letter are not significantly different ($p < 0.05$, Protected LSD).

sometimes significant, toward higher biomass and nitrogen yields in association with each other than when intercropped with corn.

In 1988, the % ^{15}N in corn grain and nonnodulating soybean seeds was higher on soil depleted of N than on non-N-depleted soil, averaged over all treatments, but the amount of ^{15}N in these crops was lower on N-depleted soil (Table 6.8). For both percent and amount of ^{15}N the opposite was observed in nodulating soybean seeds.

On N-depleted soil, the %^{15}N in corn grain was lower in the 33% corn - 66% nodulating soybean intercrop than in the 33% monocropped corn system (Table 6.8). The amount of total corn grain N in the intercrop was lower than that of the monocrop but the amount of ^{15}N was proportionately lower, resulting in the lower % ^{15}N in the intercrop. In this case N was probably transferred from nodulating soybean to dilute the total corn grain N. The % ^{15}N in corn seeds of the 66% corn - 33% nodulating soybean intercrop was lower than in the 66% monocropped corn system on N-depleted soil, also indicating potential N transfer. In the intercrop of 33% nodulating soybean - 66% nonnodulating soybean, the % ^{15}N in nonnodulating soybean seeds was lower than in the 33% corn - 66% nonnodulating soybean intercrop on N-depleted soil (Table 6.8). The total nonnodulating soybean seed N was probably diluted by transferred N from associated nodulating soybean. Similarly, it can be deduced that N was transferred from nodulating soybean to dilute the % ^{15}N in nonnodulating soybean seed N in the 66% nodulating soybean - 33% nonnodulating soybean intercrop, compared to the 66% corn - 33% nonnodulating soybean intercrop, at both soil N depletion levels. On non-N-depleted soil, N transfer to nonnodulating soybean in the 66% nodulating soybean - 33% nonnodulating soybean

Table 6.8. Concentration (%) and amount (mg m^{-2}) of ^{15}N in corn grain and in nodulating and nonnodulating soybean seeds in monocrops and intercrops, in 1988.

Treatment	Corn		Nod		NN		Total
D0	%^{15}N	mg^{15}N	%^{15}N	mg^{15}N	%^{15}N	mg^{15}N	mg^{15}N
100Nod	-	-	0.5704a	59.3a	-	-	59.3a
100NN	-	-	-	-	0.6923b	42.8a	42.8cde
33C-66Nod	0.5091c	13.8c	0.5782a	32.9c	-	-	46.8cd
33C-66NN	0.5129c^{M}	15.9c^{M}	-	-	0.6988b	19.0b	35.5e
33Nod-66NN	-	-	0.5769a	29.2c	0.7101b	22.6b	51.8abc
66C-33Nod	0.5902b	33.7b	0.6093a	13.7d	-	-	47.4cd
66C-33NN	0.5976b	32.8b	-	-	0.7741a	10.0c	42.8cde
66Nod-33NN	-	-	0.5682a	47.5b	0.5837c	9.5c	57.0ab
100C	0.6534a	48.6a	-	-	-	-	48.6bc
66C	0.6281ab	38.8b	-	-	-	-	38.8de
D1							
100Nod	-	-	0.5585a	69.2a	-	-	69.2a
100NN	-	-	-	-	0.7078bc	29.3a	29.3ef
33C-66Nod	0.5244d^{*M}	9.4c^{M}	0.5681a	44.7c	-	-	52.6b
33C-66NN	0.5787cd	11.1c	-	-	0.8273a	10.4c	21.6fg
33Nod-66NN	-	-	0.5159a	33.3d	0.7116b	16.2b	49.5bc
66C-33Nod	0.6182b*c	18.2b	0.5773a	23.7e	-	-	41.9cd
66C-33NN	0.6873ab	21.2b	-	-	0.8676a	4.3d	25.4efg
66Nod-33NN	-	-	0.5489a	51.9b	0.6047c	5.4cd	57.2b
100C	0.7240a	34.0a	-	-	-	-	34.0de
66C	0.6817ab*	32.3a	-	-	-	-	32.3e
33C	0.5803cd*	20.0b	-	-	-	-	20.0g

Table 8 continued

Depletion effects averaged over all^{z} treatments

D0	0.5849b	31.2a	0.5806a	36.6b	0.6918b	20.8a	47.4x
D1	0.6406a	21.5b	0.5538b	44.6a	0.7438a	13.1b	41.0x

Table 6.8 legend.

C = corn; Nod = nodulating soybean; NN = nonnodulating soybean; Crops preceded by 33, 66 and 100 = 33%, 66% and 100% of respective monocrop populations; D0 = non-N-depleted soil; D1 = N-depleted soil; ^{z} Excluding 33C; x = significant interaction ($p < 0.05$) of the main effects; ^{M} Missing value for one replicate; Means in a column, followed by the same letter are not significantly different ($p < 0.05$, Protected LSD); Means in a column followed by the same letter followed by an asterisk (*) are significantly different ($p < 0.05$, orthogonal contrast).

intercrop was also implied by the lower % ^{15}N in intercropped nonnodulating soybean seeds than in those of the monocropped nonnodulating soybean system. All the above examples of N transfer, except in the 66% nodulating soybean - 33% nonnodulating soybean intercrop, occurred only on N-depleted soil.

Nodulating soybean seeds did not contain different concentrations of ^{15}N in different treatments (Table 6.8). The amount of $^{15}N\ m^{-2}$ in seeds of monocropped nodulating soybean was higher than the total ^{15}N uptake of any other treatment on N-depleted soil and higher than all treatments, except the two soybean mixtures, on non-N-depleted soil.

In 1988, the coefficients of variation were high (22 to 58) for biomass and nitrogen yields in the ^{15}N direct application field experiment. This was because the plants were in a rapid growth stage when harvested and assessed on a per plant basis (Table 6.9). Although no differences, due to treatment effects, were expected between biomass and nitrogen yields, the high variability minimized the possible detection of such differences should they have occurred. Differences were not found between treatments in the greenhouse experiment, except for higher nodulating soybean root biomass and nitrogen yields at the 0 N level compared to treatments that received enriched N (Table 6.10).

In the field, N transfer was observed when enriched N applied directly to nodulating soybean petioles, resulted in higher % ^{15}N levels in adjacent corn plants than when unenriched N was applied to soybean petioles (Table 6.11). However, no such transfer was observed from nodulating soybean plants which had enriched N applied to a secondary root clump. Both the petiole and root method of applying enriched N to nodulating soybean, showed trends toward higher amounts

Table 6.9. Dry weight yield of plant biomass and plant nitrogen of corn and nodulating soybean at two levels of ^{15}N enrichment, with N applications to two plant parts and at two N application times in a 66% - 33% corn-soybean intercrop on N-depleted soil in 1988.

Treatment			Biomass (g plant^{-1})					
N	P	A	corn			soybean		
			shoot	root	plant	shoot	root	plant
E	rt	1st	7.0a	0.9a	7.9a	1.1a	0.3a	1.4a
U	rt	1st	5.9a	0.8a	6.7a	1.1a	0.3a	1.4a
E	lf	1st	9.7a	1.4a	11.1a	1.9a	0.3a	2.2a
U	lf	1st	9.3a	1.4a	10.7a	1.5a	0.2a	1.7a
E	rt	2nd	35.8a	3.9a	39.7a	3.4a	0.6a	3.9a
U	rt	2nd	17.9a	2.9a	20.9a	1.8a	0.4a	2.2a
E	lf	2nd	38.1a	5.7a	43.8a	3.5a	0.4a	3.8a
U	lf	2nd	27.2a	4.0a	31.2a	3.3a	0.4a	3.8a
			Nitrogen (mg plant^{-1})					
E	rt	1st	195a	10a	205a	35a	4a	39a
U	rt	1st	202a	15a	217a	38a	3a	41a
E	lf	1st	283a	20a	303a	93a	4a	97a
U	lf	1st	258a	18a	276a	67a	3a	71a
E	rt	2nd	687a	34a	721a	122a	9a	131a
U	rt	2nd	362a	35a	397a	62a	6a	69a
E	lf	2nd	788a	60a	848a	156a	5a	161a
U	lf	2nd	573a	42a	615a	157a	8a	165a

N - level of ^{15}N enrichment, enriched (E) or unenriched (U) nitrogen; P - plant part to which N was applied, root(rt) or leaf (lf); A - application time, 1st or 2nd; Means in a column, followed by the same letter are not significantly different ($p < 0.05$, Protected LSD).

Table 6.10. Dry weight yield of biomass and nitrogen of nodulating soybean, corn and nonnodulating soybean at three N levels with split-root systems in a greenhouse in 1988.

Trt	shoot	root	plant	shoot	root	plant
N			Biomass (g plant^{-1})			
		corn			nodulating soybean	
E	14.1a	1.7a	15.8a	5.5a	0.5a	6.1a
U	16.6a	2.1a	18.7a	5.2a	0.5a	5.7a
0	15.2a	1.9a	17.0a	6.6a	0.7a	7.4a
		nonnodulating soybean			nodulating soybean	
E	3.9a	0.4a	4.3a	3.4a	0.3b	3.7a
U	3.5a	0.5a	4.0a	5.3a	0.4ab	5.7a
0	3.2a	0.5a	3.7a	5.9a	0.5a	6.4a
			Nitrogen (mg plant^{-1})			
		corn			nodulating soybean	
E	80a	8a	89a	185a	18a	203a
U	102a	12a	115a	152a	19a	172a
0	90a	9a	99a	177a	20a	197a
		nonnodulating soybean			nodulating soybean	
E	73a	6a	79a	107a	7b	114a
U	61a	9a	70ab	154a	11ab	165a
0	52a	8a	59b	148a	15a	163a

N - nitrogen levels of 107 mg N plant^{-1}, enriched with ^{15}N (E), 107 mg N plant^{-1} of unenriched nitrogen (U) and 0 kg N plant^{-1}; Means in a column, followed by the same letter are not significantly different ($p < 0.05$, Protected LSD).

Table 6.11. Concentration (%) and amount (mg plant^{-1}) of ^{15}N in corn and nodulating soybean at two levels of ^{15}N enrichment applied to two plant parts averaged over two application times in a 66% - 33% corn-soybean intercrop on N-depleted soil in 1988.

Treatment	%^{15}N					
N P	corn			soybean		
	shoot	root	plant	shoot	root	plant
E rt	0.4734b	0.5953b	0.4810b	10.9902b	5.3627b	10.0450b
U rt	0.5003b	0.5158b	0.5060b	0.4833c	0.5142c	0.4863c
E lf	0.6872a	1.0191a	0.7264a	29.8099a	8.9056a	29.5190a
U lf	0.5004b	0.5403b	0.5034b	0.4494c	0.4854c	0.4515c
	mg ^{15}N plant $^{-1}$					
E rt	2.11a	0.13a	2.23a	9.01b	0.43a^{M}	10.34b
U rt	1.41a	0.15a^{M}	1.76a	0.24c	0.02b	0.26c
E lf	3.54a	0.42a	3.95a	35.01a	0.42a	35.43a
U lf	2.03a	0.16a	2.18a	0.50c	0.03b	0.53c

N = level of ^{15}N enrichment, enriched (E) or unenriched (U) nitrogen; P = plant part to which N was applied, root(rt) or leaf (lf); ^{M} Missing value for one replicate; Means in a column, followed by the same letter are not significantly different ($p < 0.05$, Protected LSD).

of ^{15}N plant^{-1}, in adjacent corn plants, but the trends were not significant. The levels of % ^{15}N and ^{15}N plant^{-1} in shoots of soybean plants which had enriched N applied to petioles, were about three times higher than in shoots of soybean plants which had enriched N applied to roots. Respective differences between roots were less pronounced. As expected, soybean plants to which enriched N was added were consistently higher in % ^{15}N and ^{15}N plant^{-1} than soybean plants to which unenriched N was applied.

In the greenhouse experiment, N transfer was also observed when corn plants in pots with nodulating soybean to which enriched N had been applied, had a higher concentration of % ^{15}N than corn plants associated with soybean to which unenriched or no N was applied (Table 6.12). N transfer was demonstrated more clearly when nonnodulating soybean associated with an ^{15}N labelled nodulating soybean plant, was at higher levels of both % ^{15}N and ^{15}N plant^{-1} than nonnodulating soybean in the same pot with an unlabelled nodulating soybean plant. As expected, levels of % ^{15}N and ^{15}N plant^{-1} were higher in the labelled nodulating soybean plants themselves, than in unlabelled nodulating soybean plants.

6.4. Discussion :

The accumulation of ^{15}N m^{-2} is an indicator of fertilizer N uptake. It appears to be a reflection of the accumulation of total N m^{-2} in plant material, from the soil N pool. The relationships between treatments were the same for the uptake of total N m^{-2} as for ^{15}N m^{-2}, in 1985 (Tables 6.2 and 6.3) and in 1986 (Tables 6.4 and 6.5).

Table 6.12. Concentration (%) and amount (mg plant^{-1}) of ^{15}N in nodulating soybean, corn and nonnodulating soybean at three N levels with split-root systems in a greenhouse in 1988.

Trt	shoot	root	plant	shoot	root	plant
N			(%^{15}N)			
		corn			nodulating soybean	
E	0.5071a	0.7026a	0.5252a	6.0055a	1.9653a	5.6354a
U	0.4213a	0.4921a	0.4289b	0.4748b	0.4497b	0.4718b
0	0.4498a	0.4487a	0.4498b	0.4463b	0.4311b	0.4448b
		nonnodulating soybean			nodulating soybean	
E	0.5258a	0.7991a	0.5454a	6.5636a	2.4251a	6.3167a
U	0.4584b	0.5142a	0.4652b	0.4727b	0.4468b	0.4710b
0	0.4628b	0.4463a	0.4607b	0.4550b	0.4424b	0.4540b
			(mg N^{15} plant^{-1})			
		corn			nodulating soybean	
E	0.41a	0.06a	0.47a	10.97a	0.35a	11.31a
U	0.43a	0.06a	0.49a	0.72b	0.09b	0.81b
0	0.41a	0.04a	0.45a	0.79b	0.09b	0.87b
		nonnodulating soybean			nodulating soybean	
E	0.38a	0.05a	0.42a	6.67a	0.17a	6.84a
U	0.28b	0.04a	0.32b	0.73b	0.05a	0.78b
0	0.24b	0.03a	0.27b	0.67b	0.07a	0.74b

N = nitrogen levels of 107 mg N plant^{-1}, enriched with ^{15}N (E), 107 mg N plant^{-1} of unenriched nitrogen (U) and 0 kg N plant^{-1}; Means in a column, followed by the same letter are not significantly different ($p < 0.05$, Protected LSD).

It should be noted that although 10 kg of enriched N ha^{-1} was applied in the year of less rainfall, 1985, and only 5 kg of enriched N ha^{-1} was applied in 1986, similar amounts of $^{15}N\ m^{-2}$ were taken up by respective cropping sytems containing dwarf corn, in both years (Tables 6.3 and 6.5). In 1985, it seemed that fertilizer N availability to corn plants was limited, especially in corn plants competing with nodulating soybean, which could develop better root systems than nonnodulating soybean. Corn intercropped with nonnodulating soybean took up more N m^{-2} and $^{15}N\ m^{-2}$, probably because it was under less competitive stress than corn intercropped with nodulating soybean. Monocropped nodulating soybean did not take up more N m^{-2} or $^{15}N\ m^{-2}$ than monocropped nonnodulating soybean in 1985. There seemed to be a definite upper limit on N fertilizer availability in 1985 and nodulating soybean competing against itself could not exceed the limit, even though nodulating soybean in competition with corn or nonnodulating soybean was able to aggresively compete for its share of fertilizer N.

In 1986, a clear nitrogen advantage could be attributed to nodulating soybean which increased the N content m^{-2} in the soybean mixture to almost double that in monocropped nonnodulating soybean (Table 6.4). The % ^{15}N in nodulating soybean of the soybean mixture was lower than in nonnodulating soybean of the mixture, implying that N_2 fixation was greater than N uptake in nodulating soybean even though nodulating soybean took up as much $^{15}N\ m^{-2}$ as nonnodulating soybean (Table 6.6). This probably resulted in the sparing of soil N (Vallis et al. 1967 and Vest, 1971), such that 34 nonnodulating soybean plants m^{-2} in the mixture, did not take up significantly less $^{15}N\ m^{-2}$ than 50 monocropped nonnodulating soybean plants m^{-2}. N transfer may also have been a contributing factor to the N advantage of the soybean mixture because there was a trend, although nonsignificant, toward a lower % ^{15}N in nonnodulating soybean of the mixture than in monocropped nonnodulating soybean.

In 1986, the N content in dwarf corn intercropped with nodulating soybean was significantly higher than in an intercrop with nonnodulating soybean, at 60 kg N ha^{-1} (Table 5.4). The %^{15}N was not lower in the dwarf corn of the intercrop with nodulating soybean at 60 kg N ha^{-1} (Table 6.5), suggesting that ^{15}N was not diluted by fixed N_2 from soybean. N transfer cannot be precluded in this case, but it was not detectable by the ^{15}N dilution method. For the nitrogen advantage to have occurred in the dwarf corn intercrop with nodulating soybean, some soil and fertilizer N must have been spared by nodulating soybean for corn (Vallis et al. 1967 and Vest, 1971). A large uptake of soil N by corn, including ^{15}N fertilizer, could have maintained a high proportion of ^{15}N in corn such that a low rate of N transfer from nodulating soybean would not have significantly changed the percent of ^{15}N in the corn.

In 1986, the total yields of the dwarf corn - nodulating soybean intercrops contained more N m^{-2} than the total yield of the dwarf corn - nonnodulating soybean intercrops or monocropped dwarf corn at 0 and 60 kg N ha^{-1}. The N and ^{15}N m^{-2} in the total yield of tall corn - soybean intercrops were also higher than the N content of monocropped tall corn plants (Tables 6.4 and 6.5). These relationships indicated a contribution by soybean N_2 fixation to the corn plants. This was especially important at 50% population densities of each crop (P2), where the intensification of population competition was probably no different than for monocropped corn and the greater N uptake of intercrops could not be attributed to a higher overall population. The higher ^{15}N amount m^{-2} in the total intercrop yields compared to monocropped corn indicated that the extra N was derived from fertilizer in the soil N pool, apparently spared by nodulating soybean (Vallis et al. 1967 and Vest, 1971).

The tall corn N content, based on plant counts at harvest, was 2.77 g N $plant^{-1}$ in the tall corn intercrop at S3 and P2. This was significantly higher than 1.79 g N $plant^{-1}$ in monocropped tall corn (Table 6.5). In this case, corn plant N yields clearly benefitted from an association with soybean. Eaglesham et al. (1981), reported a similar difference between corn intercropped with cowpea and monocropped corn. However, they also found a significant dilution of $\%^{15}N$ in the intercropped corn, whereas in the research reported here, the $\%^{15}N$ was not lower in intercropped corn (Table 6.5). Therefore, it seems that each corn plant competed less successfully against itself for fertilizer and soil N than against nodulating soybean plants, which could also utilize their own fixed N_2. This is consistent with the hypothesis of fertilizer and soil N sparing by N_2 fixing legumes associated with non-N_2 fixing plants (Vallis et al. 1967 and Vest, 1971). As a crop, tall corn did not take up more N m^{-2} or ^{15}N m^{-2} under monocropping than under intercropping with nodulating soybean. However, fewer corn plants in the intercrop took up as much N and ^{15}N m^{-2} as monocropped corn, such that the fertilizer N accumulated by soybean increased the ^{15}N m^{-2} in the total crop to levels above those in monocropped corn.

A nonnodulating soybean line grown in rotation after a nodulating soybean line, took up 3.7 g N m^{-2} in excess of the same nonnodulating soybean line grown continuously (Weber, 1966b). In 1988, seeds of monocropped nonnodulating soybean on non-N-depleted plots (after nodulating soybean) contained 2.0 g N m^{-2} in excess of the same treatment on N-depleted plots (after corn). More N and ^{15}N m^{-2} were taken up by all non-N_2 fixing plants on non-N-depleted soil (Tables 6 7 and 6.8). Nodulating soybean crops in the years prior to 1988 may have absorbed more soil N than they left in residual N from N_2 fixation (Johnson et al. 1975), but the net soybean absorption of soil N was less than that of corn prior to 1988.

Weber (1966b) found that nodulating soybean following nonnodulating soybean yielded 2.2 g m^{-2} more N than nodulating soybean grown continuously. He attributed the increase after nonnodulating soybean to more than stimulation of greater N_2 fixation at lower soil N levels, since the difference was maintained in the presence of N fertilizer applications. In 1988, the seed nitrogen yield difference was also 2.2 g N and 8 mg ^{15}N m^{-2} higher for monocropped nodulating soybean on N-depleted plots (after corn) than on non-N-depleted plots (continuous soybean) (Tables 6.7 and 6.8).

It does not seem probable that non-N-depleted soil N levels were high enough to substantially inhibit N_2 fixation, given the low dry matter yields of monocropped corn (5341 kg ha^{-1}) and nonnodulating soybean (1285 kg ha^{-1}) on non-N-depleted plots (Table 6.7), and the observation by Bhangoo and Albritton (1976) that soybean did not fix less nitrogen at an applied N rate of 56 kg N ha^{-1} compared to no applied N. Peterson and Varvel (1989a) reported that soybean seed yields, averaged over four years and three N levels, were 250 kg ha^{-1} higher in soybean rotated with corn than in continuously cropped soybean. It is possible that the higher nodulating soybean biomass, total N and ^{15}N seed contents on N-depleted plots, were affected favourably by rotation effects compared to the non-N-depleted plots, which were continuously planted to soybean for four years.

Ratios of soybean stover (all nonseed dry matter) over seed, show higher proportions of seed yield as the ratios decrease. Weber (1966a) noticed that the ratios increased with stresses of moisture, N or both to any soybean crop, and that a nonnodulating line consistently had higher ratios than a nodulating line. Weber (1966a) and Neves and Hungria (1987) postulated that symbiotic N may be more mobile within the plant than soil or fertilizer N, and that a high proportion of symbiotic N was sequestered to seeds. In 1988, these ratios increased in soybean monocrops from 0.84 in nodulating soybean on N-depleted plots to 0.92 on non-N-depleted plots whereas they decreased from 1.93 to 1.34 in nonnodulating soybean on N-depleted and non-N-depleted plots, respectively.

On N-depleted soil, N transfer was evident from nodulating soybean to intercropped corn based on the comparison of monocropped corn at the same 33% or 66% population. N transfer from nodulating soybean to intercropped nonnodulating soybean was determined by a comparison to nonnodulating soybean at the same population in replacement population (Willey, 1979) intercrops with corn. This may be a more accurate assessment because the soil N pool was being sampled at the same overall population intensities. On non-N-depleted soil, N transfer from nodulating soybean to intercropped nonnodulating soybean at 33% was based on two comparisons: first, to nonnodulating soybean at the same population in an intercrop with corn and second, to 100%

monocropped nonnodulating soybean. All the above examples of N transfer, except the last one, occurred only on N-depleted soil, supporting the conclusion of Eaglesham et al. (1981), that N transfer cannot be demonstrated where mineral N is plentiful.

Root N transfer has been somewhat characterized, (Eaglesham et al. 1981; Van Kessel et al. 1985) but leaf N transfer has not been evaluated. Soybean foliage can lose gaseous N under high temperatures through transpiration, amounting to a seasonal loss of 45 kg N ha^{-1} (Stutte et al. 1979). Associated corn leaves above a soybean canopy could intercept and absorb some of this nonelemental, chemically bound, water soluble nitrogen.

Nitrogen transfer was observed when enriched N was directly applied to soybean (Tables 6.11 and 6.12). Although it was not fixed N_2 that was transferred, it seems safe to assume that fixed N_2 could be similarly transferred from soybean to corn. The results of field trials involving the ^{15}N dilution method to detect N transfer were less definite because it was always possible that a lower % ^{15}N in a non-N_2 fixing plant was not due to the dilution of ^{15}N by fixed N_2 from an associated legume. However, an amount of enriched N directly applied to a legume, if detected in part in an associated plant can be said to have been transferred even though other interactions may also have occurred.

Ledgard et al. (1985) immersed leaves or petioles of clover and lucerne in solutions of enriched N, but could not detect N transfer to associated ryegrass, in the field. They did however, observe that clover N was transferred to ryegrass in pot experiments. In our research, enriched N applied to petioles in the field, was at higher levels in the soybean plants to which it was applied and in adjacent corn plants, than in unlabelled treatments. However, enriched N applied to soybean roots did not significantly demonstrate the same phenomenon. Possibly, exposed phloem at the cut in the petioles was more effective at absorbing and then translocating N than xylem underneath the endodermis of secondary roots. Phloem as an active transport system may also be more effective at transporting N than the passive transport system of xylem.

Nitrogen transfer was evident by the increased amount of ^{15}N plant^{-1} in appropriate nonnodulating soybean plants, whereas respective corn plants did not demonstrate more than an increased % ^{15}N (Table 6.12). Under conditions of direct enriched N application to nodulating soybean against a background of low supplies of soil N, increases of mg ^{15}N plant^{-1} in adjacent plants were expected. Witty and Ritz (1984) found that fixation by nodulating soybean plants was calculated to be 262 mg N pot^{-1} when nonnodulating soybean plants were the control but the same nodulating soybean plants were calculated to have fixed -3 mg N pot^{-1} when corn was the control. Corn took up N later than the soybean control and since ^{15}N enrichment of soil declined with time, it was deduced that corn took up nitrogen at a lower atom % ^{15}N excess. This may also explain the fewer examples of N transfer to corn than to nonnodulating soybean in the dilution experiment in 1988 (Table 6.8).

It has been argued that most N transfer from forage legumes to grasses may be subsequent to decomposition of nodules and root tissue (Broadbent et al. 1982, Hardarson et al. 1988). The implications for regions with short growing seasons are that only minimal N transfer could occur within one season, at the end of the season. The ^{15}N dilution method is limited by the assumption that the N uptake profiles of monocropped and intercropped reference plants are the same (Hardarson et al. 1988). Talbott et al. (1985) also addressed the concern that nodulating soybean and nonnodulating soybean do not equally utilize soil N but they concluded that the genotypes did compete equally for soil N. Rennie (1982) reported that the most appropriate reference crop for nodulating soybean was an uninoculated nodulating line on soil which had not previously grown soybean. The ^{15}N dilution method, its limitations notwithstanding, did indicate that N transfer occurred over the entire growing season of 1988, on N-depleted soil. However, the direct application of enriched N to nodulating soybean petioles demonstrated with much less ambiguity, that N was transferred from nodulating soybean to corn. This transfer ocurred too early in the growing season to have been the result of nodule breakdown and decomposition.

By the ^{15}N dilution method, with the exception of a single treatment, no significant differences were detected from nodulating soybean to non-N_2 fixing plants, on non-N-depleted soil, in any of three years. The single exception was the 66% nodulating soybean - 33% nonnodulating soybean intercrop in 1988 (Table 6.8). There was evidence in 1986, of the nitrogen sparing effect of nodulating soybean for nonnodulating soybean, dwarf corn and tall corn. However, it was on N-depleted soil in 1988, that the ^{15}N dilution method revealed N transfer from nodulating soybean to nonnodulating soybean and to corn. In addition, on N-depleted soil, direct application of enriched N to nodulating soybean by the petiole labelling method clearly showed transfer from nodulating soybean to corn. In the field, the root labelling method did not demonstrate N transfer with significant differences of % ^{15}N between enriched and unenriched treatments.

Finally, using a root labelling method in greenhouse pots, N transfer from nodulating soybean to corn and to nonnodulating soybean, was observed with statistical significance.

Section 7

GENERAL DISCUSSION

The optimum level of nitrogen application was 60 kg N ha^{-1}. Yields peaked at this level (Table 3.2), cost effectiveness was highest, LERs were most advantageous (Table 3.6) and European corn borer infestation was still about the same as at 0 kg N ha^{-1} (Table 4.1). The differences between yields and accumulated protein in corn intercropped with nodulating rather than nonnodulating soybean tended to be widest at 60 kg N ha^{-1} (Table 5.4).

The quadratic yield response of monocropped corn to applied N could indicate that soil N levels were high enough to counteract responses above 60 kg N ha^{-1}. The yields at 120 kg N ha^{-1} may also have been lower than expected, due at least in part, to high European corn borer infestations at 120 kg N ha^{-1}. It may also be that 120 kg N ha^{-1}, banded on both sides of the corn rows just after planting, was toxic to germinating corn seeds (OMAF, 1989). The corn-soybean intercrops could reasonably have been expected to yield best at 60 kg N ha^{-1} since soybean N_2 fixation and yield can be enhanced at medium N levels but inhibited at higher N levels (Bhangoo and Albriton, 1976; Eaglesham et al. 1983; LaFavre and Eaglesham, 1984). Kurtz et al. (1952) considered N fertilizer as essential to reduce competition from forage legumes as well as grasses in intercropped corn.

The most profitable corn-soybean intercrops reported by Anwarhan (1984) were at 60 kg N ha^{-1}, although gross returns were higher at 120 kg N ha^{-1}. Optimal responses at 60 kg N ha^{-1} were also found in an intercrop of corn and pole beans planted simultaneously. This intercrop had the highest LER (1.12) of the study and was one of the two most cost effective intercrops. The protein concentrations of all corn - pole bean intercrops at 60 and 120 kg N ha^{-1} were higher than monocropped corn at the same N level but the simultaneously planted intercrop at 60 kg N ha^{-1} also had a higher protein concentration than monocropped corn at 120 kg N ha^{-1} (Martin, 1985).

Intercrop treatments at 60 and 120 kg N ha^{-1}, at population densities of 67% corn : 67% soybean, 100% corn : 50% soybean or 100% corn : 100% soybean and in equidistantly spaced rows were favourable for production agriculture (Section 3). Willey and Osiru (1972) recommended planting intercrops at higher populations than monocrops until there is sufficient intensity of competition between the species to force them to fully utilize their respective parts of the environment. These treatments may not necessarily be the most opportune for detecting nitrogen transfer or optimal yield responses to applied N and N_2 fixation. The 50% tall corn : 50% soybean intercrop showed that more protein per corn plant was assimilated than in monocropped corn (Section 6) and N transfer was shown with intercrops at 33% in one component crop and 66% in the other.

On N-depleted soil, there was a clear indication of N transfer, by the ^{15}N dilution method, from nodulating soybean to corn and to nonnodulating soybean. On non-N-depleted soil, which had no more N applied than the 1 kg ^{15}N ha^{-1}, N transfer was only detected in the mixture of nodulating and nonnodulating soybean with the highest proportion of nodulating soybean (Table 6.8). The higher total N in seeds of nodulating soybean on N-depleted soil, compared to non-N-depleted soil, indicates that N transfer was more probable when nodulating soybean contained higher levels of N in a lower N environment. The conditions were suitable for such a gradient. Nitrogen transfer and yield response per unit of applied N or fixed N_2, in cereal-legume intercrops, can be more clearly seen in treatments at low N rates (Ofori and Stern, 1987) or on low soil N plots (Eaglesham et al. 1981).

It is difficult to ascertain whether high N levels eliminate the occurence of N transfer or mask it. In 1988, corn and nonnodulating soybean seed biomass yields and seed N yields were higher on non-N-depleted soil than on N-depleted soil but nodulating soybean responded inversely (Table 6.7). In intercrops in 1985 and 1986, the non-N_2 fixing crops also had higher yields at 60 than at 0 kg N $^{-1}$ but again, nodulating soybean responded inversely (Table 5.4). Nevertheless, in 1986, the significantly higher N content in corn intercropped with nodulating soybean compared to an intercrop with nonnodulating soybean, occurred at 60 and 120 kg N ha^{-1} and not at 0 kg N ha^{-1} (Table 5.4). The $\%^{15}N$ was not lower in the dwarf corn of the intercrop with nodulating soybean at 60 kg N ha^{-1} (Table 6.5), suggesting that ^{15}N was not diluted by fixed N_2 from soybean. N transfer cannot be precluded in this case because it was not detectable by the ^{15}N dilution method. For the nitrogen advantage to have occurred in the dwarf corn intercrop with nodulating soybean, some soil and fertilizer N must have been spared for corn, by nodulating soybean. A large uptake of soil N by corn, including ^{15}N fertilizer, could have maintained a high proportion of ^{15}N in corn, such that a low rate of N transfer from nodulating soybean would not have significantly changed the percent of ^{15}N in the corn. Enriched ^{15}N, applied directly to soybean under high populations and normal N rates could help to ascertain whether low levels of N transfer occur under conditions used in production agriculture.

At 0 kg N ha^{-1}, there may not have been enough N in the soil pool to spare. Nodulating soybean which contained the most N m^{-2} at 0 kg N ha ha^{-1}, could have been expected to exude some N at 0 kg N ha^{-1} for uptake by corn, but evidence is lacking to substantiate this possibility. Nitrogen transfer from nodulating soybean to corn could not be detected on non-N-depleted soil in 1988, so a background level lower than that achieved by withholding applied N, in a cropping season, appears to be necessary to detect N transfer with the ^{15}N dilution method.

Both corn and soybean crops were valuable but growing monocropped tall corn at 120 kg N ha^{-1} was more profitable than growing monocropped soybean in two different years (Table 3.6). In 1985 and 1986, in corn - nodulating soybean intercrops, the L_a ratio for corn ranged from 0.59 to 0.93 and averaged 0.74, whereas the L_b ratio for nodulating soybean, ranged from 0.28 to 0.58 with an average of 0.40. There was a general compensation trend such that lower L_as usually accompanied higher L_bs. For example, the two highest L_bs were at the S4 spacing pattern favouring soybean growth but L_as at S4 were the lowest. The highest L_a, 0.93, was measured at 100% corn : 50% soybean and it corresponded to the lowest L_b. The aggressivity coefficient, L_a - L_b (Mead, 1986), for average values was 0.34, indicating a substantial spread between the two crops. Another index of dominance is the competition ratio, L_a/L_b (Mead, 1986); on average this value was 1.85. In intercrops, corn was almost twice as competitive as soybean in approaching respective monocrop yields. Given the greater value of corn ha^{-1}, it is prudent to arrange populations and spacing patterns to allow the expression of corn aggressivity in intercrops of production agriculture.

Twin row spacing patterns for monocropped corn, similar to S4, have increased the yield of corn, albeit averaged over water management levels including two irrigation treatments (Karlen and Camp, 1985). Therefore, it seemed plausible that a short statured soybean intercrop in the wide spaces between twin corn rows could intercept light which otherwise would be wasted, and thereby increase land use efficiency (W.T. Federer, Cornell Univ. pers. comm.). However, Cordero and McCollum (1979) had noted a 12% decrease of monocropped corn yields in twin row patterns compared to conventional 97 cm rows and a 17 to 22% decrease when soybean or snapbean was planted in the wide interrow space. In our experiments the corn yield in S4 intercrops was reduced 37 to 41% compared to monocropped corn in conventionally spaced rows. This may be explained by the lower population of intercropped corn (50% or 67% of the monocropped corn population), a relatively short growing season in the Ottawa region or excessive population pressure from intercropped soybean at 50% or 67%. In comparison to intercrops in equidistantly spaced alternate rows, S3, where corn yields were reduced by 30% or less, the twin row S4 intercropping system depressed corn yields to unacceptable levels (Table 5.5).

The competitive advantage of a corn crop can be shifted in favour of corn by planting it prior to the other intercrop component or the competitive advantage can be curbed by a delayed planting of corn (Nnko and Doto, 1980; Francis et al. 1982 and Knapp, 1982). In the short growing season of the Ottawa region, it was advantageous for the corn component if it was planted prior to pole beans but LERs and cost effectiveness of the entire intercrop were negatively influenced at the most effective N level, 60 kg N ha^{-1} (Martin, 1985). It does not seem useful to manipulate corn-soybean competition by planting at two different dates since; 1) it is more time-consuming and costly for farmers, 2) competition can be adjusted with spacing patterns and population densities (Tables 3.5 and Section 5) and 3) late-planted soybean may flower too close to the time of corn silking resulting in excessive competition for water and nutrients at this critical time (Shaw, 1988).

LERs were calculated with common denominators for L_a and L_b (Tables 4.4 and 5.7) for statistical comparisons (Oyejola and Mead, 1982). ANOVA analysis of LERs has been seen as inappropriate because they consist of ratios (Wijesinha et al. 1982). A different denominator for each L_a or L_b can more accurately meet the criterium for evaluating only intercrops and monocrops under the same management level. However, some spacing patterns, N levels or population densities etc. may not be practical under monocropping and have frequently been included as monocrops simply to meet the same management level criterium. Unfortunately, the resulting LERs cannot be rigorously compared and exaggerated LERs are often the result of inappropraiate comparisons to unacceptably low monocrop yields. Mead (1986) suggested that one monocropping treatment, at the standard monocropping management level, is sufficient for each component crop being evaluated. Intercropping studies should conserve the precision of the experiment to compare various intercropping regimes rather than using too many experimental units for monocrops to compare intercrops to monocrops. Production agriculture can be more meaningfully compared in groups of LERs with common denominators. The LERs of Table 3.6 might more realistically be evaluated with one dwarf corn monocrop and one tall corn monocrop, each at 120 kg N ha^{-1}. The LERs of intercrops in this study would then be lower at 0 kg N ha^{-1}, higher at 60 kg N ha^{-1}, and unchanged at 120 kg N ha^{-1}.

The L_b values of soybean may be called into question because soybean, not usually grown as a forage monocrop, has been evaluated as an intercrop over a monocrop in the LERs. Soybean has a history of utilization as a high-protein forage monocrop. When used as a hay crop, soybean was found to be as rich as alfalfa in protein and worth 80 - 90% of the feeding value of alfalfa hay. Soybean could match the alfalfa feeding value if seeds were well formed on late soybean hay and coarse stems were chopped to avoid wastage by cattle (Morrison, 1959). Horses, mules, swine and poultry have also responded satisfactorily to well cured and ground soybean hay as a supplement. If the fall weather was unsuitable for haymaking, soybean was ensiled in proportions of 25 to 50% with corn or sorghum. It was also frequently grown as an intercrop (Morrison, 1959). Although not considered a forage crop today, soybean can reasonably be assessed in LERs as a forage monocrop. In addition, it is still usually grown as a protein source to be added to feed.

The tall corn hybrid, Coop S259, was selected because it is a 2500 CHU hybrid and its yield index was 107 in a 2500-2600 CHU area in 1982 and 1983 (Ont. Corn Comm., 1984). Assuming moisture levels of 65%, monocropped silage yields of Coop S259 at 120 kg N ha^{-1} were 29,708 kg ha^{-1} in 1985 and 39,846 kg ha^{-1} in 1986, higher than Ontario averages of 28,224 and 28,672 kg ha^{-1}, respectively (OMAF, 1988). However, later hybrids have the potential to yield even better. Given that CHUs in Ottawa tend to be slightly higher than in the surrounding region (Dr. L. Dwyer, LRRI, Agric. Canada, pers. comm.), and given that hybrids for silage can be 100 to 200 CHUs later than grain corn (Upfold and Morris, 1987), it might have been better to have chosen a later hybrid. The time during and just after tassling, anthesis and silking is when corn yields are most susceptible to moisture stress (Shaw, 1988). This period, delayed a few days in a later hybrid, might have conflicted less with soybean podfilling in late July, resulting in greater intercrop, as well as monocrop corn yields.

Yields were not significantly affected by corn hybrids used in this experiment but LERs tended to be lower in dwarf corn intercrops than in tall corn intercrops, especially in 1985 (Table 3.6). In 1985, both component crops in the dwarf corn intercrops had a consistent trend toward lower biomass and protein yields than in tall corn intercrops at the same levels of N (Tables 3.1 and 3.3). Tall corn appeared to have more leaves in a position to intercept light directly than dwarf corn with shorter internodes. Dwarf corn seemed to shade it's own leaves and those of soybean more than tall corn as observed by Woolley and Roderiquez (1987) and according to the comments of Donald (1963). However, it is speculative to propose mechanisms for different responses of dwarf corn and tall corn, which were often marginal in any case. The interception of photosynthetically active radiation (PAR), leaf angle and leaf area index (LAI) were not measured in this experiment and as mentioned previously, corn hybrid effects were to some extent confounded with population densities. Another confounding factor could be that dwarf corn is rated for 2400 CHU in Eastern Ontario (Dr. R. Hamilton, PRC, Agric. Canada, pers. comm.) whereas tall corn is a 2500 CHU hybrid.

Maple Arrow, a 2600 CHU soybean variety, Nattawa, a 2600 CHU variety and the nonnodulating selection from a cross with Evans, a 2750 CHU soybean variety, are well-adapted to the Ottawa region and mature within several days of each other (Dr. H.D. Voldeng, PRC, Agric. Canada, pers. comm.). The grain yield of monocropped soybean assuming a harvest index of 0.40 and 14% moisture was 1881 kg ha^{-1} in 1985 and 2999 kg ha^{-1} in 1986, compared to Ontario average yields of 2490 kg ha^{-1} in both years (OMAF, 1988). Later maturing and higher yielding varieties have been considered for corn-soybean intercropping since soybean used for forage does not have to achieve complete maturity. However, the days to flowering and days to maturity were both significantly delayed in soybean intercropped with corn, compared to monocropped soybean (Sharma and Mehta, 1988). Conversely, Makena and Doto (1980), observed that the days to flowering of soybean were hastened by intercropping. Osiru (1980) identified the earliest bean genotypes as best for overall intercrop yields in intercrops with corn A soybean variety that flowered too late, could compete excessively with the reproductive stages of corn. A preferred variety would be one that matures later but flowers at the same time or earlier than Maple Arrow, to avoid extra competition for moisture at the most stress sensitive stages of corn development.

Nodulating soybean, an aggressive competitor for soil N (Johnson et al. 1975), did take up more $^{15}N\ m^{-2}$ than other treatments, on N-depleted and non-N-depleted soil, in 1988 (Table 6.8) According to the viewpoint of Johnson et al. (1975) non-N-depleted soil may have been somewhat N-depleted as well but less so than soil N-depleted by corn. Lower amounts of N and $^{15}N\ m^{-2}$ were taken up by corn and nonnodulating soybean grown on depeleted plots than on nondepeleted plots, an indication of at least relative depletion (Table 6.4). Searle et al. (1981) showed that nitrogen uptake by wheat following soybean was 34 kg N ha^{-1} higher than wheat following corn. Wheat N uptake following a corn-soybean intercrop was also significantly higher, by 7 kg N ha^{-1}, than after monocropped corn.

At sufficient N levels, July precipitation has been reported as the single most important abiotic factor relating to corn yields (Ashgari and Hanson, 1984). In our experiments July precipitation was 67.2 mm in 1985 and 144.4 mm in 1986 (Environment Canada, 1985 and 1986). The average corn yields in 1986 were 3330 kg ha^{-1} greater than those in 1985, a 35.5% increase (Table 3.2).

In the mixture of nodulating and nonnodulating soybean, the genotypes competed equally in 1986. However, in the dry year of 1985, nodulating soybean produced about three times the yield of nonnodulating soybean. Sinclair et al. (1988) distinguished the response of nodulating soybean to decrease N accumulation rates under moderate droughts from the response of maintaining nodule numbers and dry weights, except under a severe drought. The August precipitation was similar in 1985 at 71.1 mm to that in 1986 at 99.0 mm (Environment Canada, 1985 and 1986). Nodulating soybean may have recovered it's N_2 fixation capacity after the drought stress, which occurred during the early soybean reproductive period in July 1985, was relieved. The crude protein yield of nodulating soybean in the soybean mixture was 3.66 times higher than nonnodulating soybean in 1985, while there was no significant difference in 1986 (Table 5.2). Nevertheless, monocropped nodulating soybean protein yields were 94% higher in 1986 than in 1985 and those of nonnodulating soybean were only increased by 9% from 1985 to 1986, an indication that N_2 fixation was restricted by drought stress conditions in 1985.

Allen and Obura (1983) noted lower yields in a dry season and found that corn-soybean intercrops responded more to irrigation than monocropped corn. However, they did not apply N to intercrops as they did to monocropped corn and this limitation may have been confounded with that of low moisture, by exacerbating the overall stress to the intercrop. Kurtz et al. (1952) concluded that corn - forage legume intercrops need adequate amounts of both nitrogen and water. In our study, where irrigation was not a factor, intercrop as well as monocrop yields increased significantly from 0 kg N ha^{-1} to 60 kg N ha^{-1}, by averages of 31.6% in the dryer year of 1985 and by 29.9% in 1986 (Table 3.2). Liebmann (1989) ascertained that total seed yield of intercropped barley and field pea, averaged over two irrigation levels, increased with increasing N fertilizer applications in a relatively dry year only. Barley seed yield alone consistently increased with added N in two years, but the response was greater in the dryer year.

Intercrop protein should be considered for the complementary amino acid profiles of corn and soybean. Methionine and cystine are at adequate levels in corn but deficient in soybean, and lysine, commonly deficient in corn, is at high levels in soybean (Orthoefer, 1978) Carbohydrate in whole soybeans also has value in livestock rations. In a feeding trial with sheep (Murphy et al. 1984), corn-soybean silage had higher protein, lignin and ash, and lower cell wall constituents and acid-detergent fiber than corn silage, but the digestibilities of all components including energy were the same. An intercrop of corn and soybean for grain production had lower energy values than monocropped corn but the intercrop gave the higher yield of total fat (ether extract) and methionine, as well as of crude protein when compared to each monocrop (Beets, 1977).

The actual value of higher protein contents of corn-soybean silage assessed on plant dry matter before ensiling (Table 3.2) should be determined in regulated feeding trials. Depending on the overall diet, ruminants may obtain about equal to somewhat less protein value from one kg of nitrogen in ensiled soybean plants compared to one kg of nitrogen in soymeal (D. Viera, Agriculture Canada, pers. comm.). McCormick et al. (1983), stated that conventional protein supplements could be substituted by rolled whole soybean seeds on an equal protein basis. The daily gain of beef calves was similar with either whole soybean seeds or soymeal as a protein supplement. Ruminants can derive amino acids for their metabolism from rumen microorganisms which utilize raw soybean protein (Stern et al. 1980). The higher protein amounts accumulated by intercrops (Table 3.2) may therefore have been worth the equivalent value of the same actual protein in soymeal. In 1987, the corn-soybean silage from the intercrop treatment (Table 5.7) was fed to beef steers which appeared to find it palatable and responded very well. In 1981, an informal feeding trial was also conducted by a farmer who did not find it necessary to add supplemental protein meal or hay to corn-soybean silage when it was fed to dry cows and heifers (M. McEwen, farmer, North Gower, Ont., pers. comm.).

The overall objective of this research was to test the land use efficiency of intercropping corn and soybean in our cool temperate region. Although Ottawa is at 45^{o}N latitude, in an area of 2500 - 2600 Corn Heat Units, many of the advantages of intercropping commonly reported in longer growing season areas, were also seen here. Most LERs were higher than 1.10 and protein concentrations of corn-soybean silage were up to 10.76%. A common pest, European corn borer, was reduced by intercropping. Under normal rainfall, dwarf corn had higher protein and yield levels when intercropped with nodulating soybean rather than when intercropped with nonnodulating soybean. Finally, on N-depleted soil, despite the short season for soybean N_2 fixation and subsequent decomposition of nodules, N transfer was detected from nodulating soybean to nonnodulating soybean and to corn by the ^{15}N dilution method.

Section 8

SUMMARY AND CONCLUSIONS

The overall objective of this research was to test the land use efficiency of intercropping corn and soybean in our cool temperate region. Results showed that corn-soybean intercrops at 60 and 120 kg N ha^{-1} in Ottawa, Ontario, produced higher yields and protein levels more cost efficiently than separate monocrops of corn and soybean.

Corn and soybean each yielded higher in monocrops than the respective component crops under intercropping. However, LERs ranged from 0.97 to 1.23 in 1985 and 1986 and most were higher than 1.10 at all N levels and for both corn hybrids. Protein concentrations of corn-soybean silage were on average, up to 2.15 percentage points greater than those of corn silage. A general trend of higher protein yield ha^{-1} in intercrops compared to corn monocrops was significant in 1986.

Dwarf corn yields, on average, were not different from tall corn yields but the total silage protein concentration in 1985 and 1986 and the protein yield in 1986 were lower for dwarf corn than tall corn. LERs also tended to be lower in dwarf corn compared to tall intercrops, especially in 1985.

Total biomass and protein yields averaged over corn hybrids and cropping systems had a quadratic response to applied N, increasing from 0 to 60 kg N ha^{-1} and decreasing slightly between 60 and 120 kg N ha^{-1}, in both years. Increasing N applications resulted in increasing total silage protein concentrations in both years. All treatments at 0 kg N

ha^{-1} were less cost effective than the standard treatment, monocropped tall corn at 120 kg N ha^{-1}.

The most cost effective treatment in 1985, tall corn intercropped with soybean at 60 kg N ha^{-1}, had a \$135 ha^{-1} advantage over the standard treatment. In 1986, this intercrop had a \$132 ha^{-1} advantage which was improved to \$261 ha^{-1} at a population of 100% corn and 50% soybean.

The optimum intercrop population of 100% tall corn and 50% soybean was the only intercrop to produce almost the same yields of biomass and protein in the corn component crop alone compared to monocropped corn. The total biomass yields of tall corn - soybean intercrops at 60 kg N ha^{-1} were higher at both populations of 100% corn : 100% soybean and 100% corn : 50% soybean than at either 67% corn : 67% soybean or 50% corn : 50% soybean.

In 1986, nonnodulating soybean and dwarf corn had higher protein and yield levels when grown in association with nodulating soybean compared to an association of either nonN_2 fixing crop with nonnodulating soybean. However, in 1985, a year of less rainfall, both nonN_2 fixing crops yielded less in association with competitive nodulating soybean than when intercropped with low yielding nonnodulating soybean.

Spacing patterns did not affect dwarf corn intercrop yields in 1985 In 1986, tall corn and dwarf corn were not affected by each others spacing pattern but tall corn yields were higher in alternate 40 cm rows with soybean than in the S4 twin row spacing pattern. In 1987, the total crop grain yield and LER of the intercrop was higher than in the stripcrop.

Intercropping reduced European corn borer infestation in tall corn in 1985 and in both corn hybrids in 1986. Dwarf corn was less infested by European corn borer than tall corn in 1985 and 1986 and under both monocropping and intercropping. Infestation levels were not different between 0 and 60 kg N ha^{-1} but did increase from 60 to 120 kg N ha^{-1}. The failure of total yields to increase from 60 to 120 kg N ha^{-1} may have been due, at least in part, to the higher European corn borer infestations at 120 kg N ha^{-1}.

Nitrogen transfer from nodulating soybean to corn and to nonnodulating soybean was not detected by the ^{15}N dilution method on non-N-depleted soil, in any of three years, except in one treatment. In the single exception, N transfer was seen from nodulating soybean to nonnodulating soybean in an intercrop with the highest proportion of nodulating soybean, on non-N-depleted soil. There was evidence in 1986 of the nitrogen sparing effect of nodulating soybean for nonnodulating soybean, dwarf corn and tall corn. However, it was on N-depleted soil in 1988, that the ^{15}N dilution method revealed N transfer from nodulating soybean to nonnodulating soybean and to corn, at several intercrop populations.

Direct application of enriched ^{15}N to nodulating soybean by the petiole labelling method clearly showed N transfer from nodulating soybean to corn. The root labelling method did not indicate significant N transfer in the field. However, in greenhouse pots, the root labelling method demonstrated significant N transfer from nodulating soybean to corn and to nonnodulating soybean.

Section 9

CONTRIBUTIONS TO KNOWLEDGE

Corn-soybean intercropping, European corn borer infestation and nitrogen transfer have been researched previously. However, this is the first study to concurrently investigate all of the above phenomena and to explore their interactions. The following are considered to be specific contributions to original knowledge:

1. At 45°N latitude, corn-soybean intercrops had LERs up to 1.23, silage protein concentrations up to 10.76% and economic advantages up to \$261 ha^{-1}. This is the first research report to demonstrate these agronomic benefits of corn-soybean intercropping in a cool temperate region as far north as 45° N latitude.

2. In 1986, corn intercropped with nodulating soybean had higher protein yields than corn intercropped with nonnodulating soybean. Intercropping evaluations seldom include comparisons of cereal-legume intercrops with treatments of both nodulating and nonnodulating legumes (Elmore and Jackobs, 1986). This is the first field experiment to confirm the contribution to the intercrop of N_2 fixing legume nodules, by growing corn as an intercrop with nonnodulating soybean as well as nodulating soybean.

3. In 1985 and 1986, the biomass yields of dwarf corn were similar to those of tall corn but protein concentrations were lower in dwarf corn than in tall corn. In 1986, protein yields were lower, in dwarf corn than in tall corn. This is the first research report to test the suitability of dwarf corn versus tall corn for yield and protein

responses in a corn-soybean intercrop. It is also the first time the respective spacing patterns of dwarf corn and tall corn, each with their own population density, have been compared in corn-soybean intercrops. The corn hybrid yields were found not to be different in one another's spacing patterns. Thompson et al. (1976) reported the effects of corn height on soybean only, when intercroppped with both tall and short maize in the tropical region of Tanzania.

4. Under the conditions of this study, in 1987, intercropping was superior to strip cropping. Others have compared strip cropping of corn and soybeans to monocrops of these crops and many have assessed corn-soybean intercrops in relation to monocropping but this is understood to be the first report of a corn-soybean intercrop compared to a corn-soybean strip crop.

5. In 1985, the percent infestation of European corn borer was reduced from levels in monocrops in tall corn by intercropping with soybean. In 1986, corn borer infestations were reduced in both tall and dwarf corn, by intercropping rather than monocropping. This is the first research report to assess the effect of corn-soybean intercropping on European corn borer infestation.

6. In a pot study, European corn borer larvae survival was found to increase with increasing N applications to susceptible corn hybrids (Cannon and Ortega, 1966). Lambert et al. (1987) did not observe consistent responses of European corn borer percent infestation to N applications in field plots of corn and clover. The present report is the first to show the greatest European corn borer infestation at the highest of three rates of N applied to corn, in the field.

7. Tall corn was shown to be infested more by European corn borer than dwarf corn under both intercropping and monocropping conditions. Corn

hybrids have been compared for susceptibility to European corn borer but this is the first research report to compare European corn borer infestation in dwarf and tall corn under intercrops and monocrops.

8. The direct ^{15}N labelling method corroborated the occurrence of N transfer, indicated by the ^{15}N dilution method. This is the first research report of a field experiment to test the ^{15}N dilution method of nitrogen transfer from soybean to corn. It is also the first time N transfer has been tested by directly applying ^{15}N to soybean plants in the field.

9. The soybean petiole ^{15}N labelling method was more effective than the split root ^{15}N labelling method, in detecting N transfer. This is the first research report of a greenhouse or field experiment to compare the effectiveness of directly applying ^{15}N to a soybean plant through the petioles rather than through a split root system for the purpose of detecting ^{15}N in an adjacent plant.

10. Nitrogen transfer was detected in several treatments on N-depleted soil but only in one treatment on non-N-depleted soil, with or without applied N, over three field seasons. This is the first research report to evaluate N transfer in an experimental design with both N-depleted and non-N-depleted soil treatments.

Section 10

SUGGESTIONS FOR FUTURE RESEARCH

1. A feeding trial should be done to compare the effect of feeding corn-soybean silage to the effect of feeding corn silage adjusted to the same protein level with added soymeal supplement. A cost-effectiveness analysis should also be included.

2. A complete range of determinations of corn and corn-soybean silage feed value parameters, especially pertaining to energy and protein, should be done after the ensiling process to clarify the relative value of corn-soybean intercrops and corn monocrops.

3. Intercrops of corn and soybean should be compared to monocropped corn and monocropped soybean at population densities of 133%. This could help to differentiate between population density effects and intercropping effects in intercrops with an overall population density of 133%.

4. Nodulating (Rj1) and nonnodulating (rj1) soybean genotypes which differ only at the Rj1 gene, should be compared in intercrops with corn at 45° N even if full soybean maturity is not reached before silage harvest.

5. Since the whole soybean plant is harvested from corn-soybean intercrops, late maturing and high yielding soybean lines should be tested in intercrops for silage at 45° N.

6. Determinations of N_2 fixation of soybeans under several N rates in soybean monocrops and intercrops could test the idea that associated corn reduces inhibition of N_2 fixation by "mopping up" excess fertilizer N.

7. The highest yielding corn hybrids in monocrops may not compete effectively or may compete too aggressively with soybean. A variety of corn hybrids with different CHU ratings should be selected for efficient intercropping competitiveness such that optimum corn and soybean biomass and protein yields are realized.

8. European corn borer infestation should be eliminated in some monocrop and intercrop treatments to separate the effect of European corn borer from the effect of soybean competition on reduced corn yields.

9. For several years, the cost effectiveness of corn-soybean intercropped continuously or in rotation with alfalfa should be compared to the cost effectiveness of corn silage and alfalfa grown separately but in rotation, on the equivalent land area.

10. Enriched ^{15}N should be applied to nodulating soybean intercropped with corn at production N levels and at high populations, to determine whether N transfer can also be detected under conditions used in production agriculture in which it may be masked, and was not detected by the ^{15}N dilution method.

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