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Title: Establishment of Kura Clover for Seed with Wheat Intercrops

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Kura clover (*Trifolium ambiguum* M. Bieb.) is slow to establish and has low seed yields the year after establishment. Intercropping a cereal grain during clover seed field establishment could provide additional revenue to seed growers, provided that intercropping did not jeopardize future clover seed yields. Factorial combinations of spring- and fall-planted kura clover monocultured, companion-intercropped with wheat (*Triticum aestivum* L.) at two row widths, and relay-intercropped with wheat at two row widths were compared. Spring-planted clover established better than fall-planted clover as measured by percent ground cover. Both spring- and fall-planted kura clover were better established when relay-intercropped than when companion-intercropped. Spring-planted kura clover relay-intercropped with fall wheat established better than any other treatment combinations, comparing favorably with spring-planted kura clover monocultures at 18 months from planting. Kura clover generally did not affect wheat yields. Wide and narrow row spaced wheat generally affected kura clover similarly, with narrow-spaced wheat out yielding wide-spaced

wheat. It was concluded that relay-intercropping fall wheat into spring-planted clover does not adversely affect clover establishment and could therefore provide more cash revenue than monocultured clover during the clover establishment period.

Establishment of Kura Clover for Seed
with Wheat Intercrops

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INTRODUCTION

Kura Clover

Trifolium ambiguum (M. Bieb.) is a perennial, rhizomatous clover native to Crimea, Caucasian Russia (Azerbaydzhan, Armenia, Georgia), Eastern Turkey, and Northern Iran. It is found in both mountainous and steppe areas. *T. ambiguum* is commonly known as kura (from the Kura river in Georgia, USSR), Caucasian, honey, or Pellet's clover. Populations within the species show resistance to drought, water logging, cold, and adaptation to various soil types including highly acid (pH 4.9). Wide differences in morphology have led to several described varieties (Bryant, 1974).

Morphological variation is attributed to naturally occurring diploid ($2n = 16$), tetraploid ($2n = 32$) and hexaploid ($2n = 48$) races (Speer and Allinson, 1985). Kura clover cross pollinates and is highly self-incompatible, but some selfing may occur (Townsend, 1970). Crosses of kura clover with white clover (*T. repens* L.) and alsike clover (*T. hybridum* L.) have been made. Only very limited success has resulted from white clover inter-specific crosses.

Kura clover is hard-seeded with reports of between 40 to 60% (Bryant, 1974) and 90% (Khoroshailov and Fedorenko, 1973) hard seed. Scarification, both acid and mechanical, alleviates most of this problem. Optimum scarification resulted from 24 minutes in concentrated sulfuric acid (Speer and Allinson, 1985).

Poor seedling vigor and a long establishment period are common with kura clover. Herbage production during establishment is low (Spencer and Hely, 1982), being as much as 3.6 times less than white clover (Spencer et al., 1975). Established stands of kura clover can be quite productive. A five year old stand produced 13,250 kg ha^{-1} of forage under optimal conditions, comparing well with white and red clover (*T. pratense* L.) (Stewart and Daly, 1980). Most kura clover biomass is below ground. Dear and Zorin (1985) reported that the shoot to root dry matter ratio of four year old kura clover was between 0.16 and 0.20, depending on ploidy level. Above-ground dry matter production of kura clover increases with time from establishment, while yields for white clover decreased (Spencer and Hely, 1982). Kura clover also responds positively to phosphorus applications, which increases the root to shoot ratio, especially in the hexaploid forms. Under drought conditions severe enough to cause mortality in white clover, kura clover continued to produce harvestable amounts of forage. Drought tolerance is a result of a large root and rhizome system.

Kura clover flowers under long-day conditions. Flowering has been observed from mid-May through mid-September at 41° 30' N latitude (Speer and Allinson, 1985). Kura clover has a short corolla tube and has high sugar content nectar, making it favored by both bees and beekeepers.

Kura clover is valuable as an erosion control and soil conservation species due to its vigorous below-ground growth and tolerance to adverse climatic conditions (Bryant, 1974). Kura clover has well-developed drought and low-temperature induced dormancies, may live to 10 or 12 years, and seems to prefer non-calcareous clays and clay loams (Bryant 1974).

Kura clover is resistant to many viruses which infect other forage legume species including alfalfa mosaic, bean yellow mosaic, clover yellow mosaic, red clover vein mosaic, white clover mosaic, pea stunt, and clover yellow vein (Barnett and Gibson, 1975). Kura clover is more digestible and has greater percentage of crude protein and calcium and magnesium than alfalfa, making it an excellent fodder crop (Allinson et al., 1985). Early problems with nodulation have now been overcome and commercial inoculants are available (Speer and Allinson, 1985).

Seed production of kura clover has not been extensively studied. Insect pollination is required with an optimum honey bee hive density of 12 per hectare (Bryant, 1974). Seed production the year of planting has been reported to be low (78.1 kg ha^{-1}) (Bryant, 1974). As much as 508.7 kg ha^{-1} of seed was produced by researchers in Quicksand, KY from an 8 year old field (Anon, 1989). Only Rokzov (1950) has reported high seed yields of first year plantings. Exact vernalization and photoperiod requirements for kura clover are unknown at this time (Steiner, personal comm., 1990). A 30 cm row spacing and 8 to 10 kg ha^{-1} planting rate was found to be optimal for kura seed production (USDA Soil Conservation Service, 1985). Kura seed is not readily available and further research and commercial use of this species will be hampered until seed availability improves (Bryant, 1974; Speer and Allinson, 1985).

Intercropping

Definitions

The complexity of multiple cropping patterns has given rise to a complex set of terminology. The terms used to describe the different types of multiple cropping are becoming uniform. Andrews and Kassam (1976) published a list of terms which were later endorsed by Vandermeer (1989) and Francis (1986), who urged others to follow this terminology to reduce ambiguity. Multiple cropping is the most general term and refers to crop species intensification in either time, or space, or both. Multiple cropping is the production of more than one crop on a field during a growing season.

Multiple cropping takes two general forms: sequential cropping and intercropping. Sequential cropping refers to growing two or more crops on a field in sequence. The crops are grown as monocultures and do not biologically interact. As such, this represents a temporal cropping intensification and might be thought of as a short rotation. Ratoon cropping is a special form of sequential cropping in which at least one additional crop is harvested from the regrowth of the original planting.

Intercropping is defined as the growing of two or more crops on the same field at the same time. A component crop is an individual species within an intercrop mixture. Intercropping intensifies cropping both temporally and spatially, and implies that the crops will biologically interact. More precise terms for the description of the plant-spacing geometry are mixed-, row-, and strip-intercropping. Mixed-intercropping refers to the planting of two or more crops in no distinct row pattern. Row-intercropping describes a planting pattern which has at least one of the crops planted in rows. A planting geometry which has the crops planted in strips of more than one row is termed strip-intercropping. Relay-intercropping (also relay cropping) refers to intercropping two or more species for only a portion of their life cycles and implies a delayed planting date for one of the species.

Objectives and Use of Intercropping

As with any cropping technique, the use of intercropping in farming systems should be justified by comparative advantages to other systems.

Some potential advantages of using intercropping systems are: (i) increased productivity; (ii) improved resource usage (e.g. land, labor, water, time, nutrients); (iii) reduced pest damage; and (iv) Socio-economic advantages (e.g., stability, economics, human nutrition, environmental conservation) (Vandermeer, 1989).

Intercropping is thought of as a system primarily for the developing tropics, but is surprisingly common, and may become of greater importance, in the more temperate and technologically advanced areas of the world (Francis, 1986). The most common temperate-region intercropping systems are managed pastures, rangelands, and forest systems (Gomm et al., 1976). In addition, intercropping is also used to produce corn (*Zea mays* L.), soybeans (*Glycine max* L.), wheat, barley (*Hordeum vulgare* L.), and oats (*Avena sativa* L.) among other crops.

Cereal and Legume Systems

Rao (1986) cites many tropical intercropping systems whose component crops include at least one cereal and one legume. Five systems are cited from India, including combinations of millet (*Pennisetum spp.*) and sorghum (*Sorghum bicolor*) with soybean, groundnut (*Arachys spp.*), mung bean (*Vigna radiata*), cowpea (*Vigna spp.*), pigeonpea (*Cajanus cajun*), and chickpea (*Cicer arietinum*). Six examples from Central and South America include combinations of maize, beans (*Phaseolus spp.*), castor (*Rieinus communis*), cowpeas, perennial cotton (*Gossypium spp.*), and cactus (*Opuntia spp.*). Okigbo and Greenland (1976) cite six cereal and legume intercropping systems in Africa, some of which have as many as seven different crop species growing together.

Such high-intensity systems rely heavily on long growing seasons and human labor for field operations and are not practical in more temperate and industrialized regions were the growing season is shorter and the reliance on machinery to replace human labor is greater. However, this does not mean that cereal-legume intercropping systems can not be or are not practiced in temperate regions, only that they must be adapted to fit the specific needs of those regions.

Intercropping and Seed Production

Intercropping and seed production may seem to be highly incompatible, but in certain cases seed crops can be grown with intercrops. Intercropping during the establishment period of slow-maturing perennial seed crops is a good example. Under these circumstances, seed crop and intercrop production may not even overlap. Certified seed production must meet certain legal standards regardless of being intercropped. Registered seed fields must be free from weedy species and seed-borne disease and must contain only one cultivar of the given crop to maintain seed purity (Copeland and McDonald, 1985). Criteria for the choice of intercrop species are that its seed should be easy to separate from the crop seed if harvests overlap, and that the production of the intercrop does not reduce or eliminate the production of seed. Optimally, the intercrop would not be harvested with the seed crop. The intercrop should be able to be controlled by the use of selective herbicides if volunteer plants of the intercrop are a problem. Some examples of intercropped seed production include oats and red clover seed; wheat and subterraneum clover (*T. subterraneum* L.) seed (Gomm et al., 1976); and wheat and orchargrass (*Dactylis glomerata* L.) or red fescue (*Festuca rubra* L.) (Chastain and Grabe, 1988 and 1989).

Ecology of Intercropping

Many intercrops are in use and have been researched for temperate climates, but results from these studies have been varied. Many studies cite ecological reasons as the explanation for their results.

Competition results when two or more organisms require the same resources. The more similar the requirements, the more intense the competition when resources are limited. Intraspecific competition is often more intense than interspecific competition because two members of the same species will often have more similar requirements than two different species. (Barbour et al., 1980). Competition between intercropped species will vary in relation to the overlap between their niches.

Perennial forage legumes and cereals have proven to be good intercrop mixes in large part because of their differences. Cereals are generally r-selected strategists, being short-lived, rapidly maturing, and devoting a large portion of their photosynthates to reproductive tissues. Perennial forage legumes are more k-selected, being long-lived, slow to mature, and devoting much of their photosynthate production to storage organs such as roots and rhizomes. R-selected species are capable of causing intense competition, but for relatively short periods of time. K-selected plants are able to withstand short periods of competition by using stored reserves and by delaying reproduction until more favorable periods when resources are not in short supply.

Light Competition: The most intense arena of competition may be the light environment. Competition for light during intercropping may completely eliminate legume populations having high-light requirements (Chamblee, 1972). Solar radiation contains radiant energy from the wavelength of 0.12 to 100 μm (Weast, 1984). Only the wavelengths from about 0.4 to 0.7 μm are photosynthetically active radiation (PAR). In this review, the term light will refer only to PAR.

Black (1957) defines "sun species" as those plants which have maximum relative growth rates (RGR = $g\ g^{-1}\ day^{-1}$) at light intensities greater than full sunlight. Sun species include subterranean clover, white clover, red clover, alsike clover, and alfalfa (*Medicago sativa* L.). When any of these small-seeded forage legumes receive reduced levels of light, a lowered RGR is expected.

Evers (1989) found that decreasing the amount of light available to berseem clover (*T. alexandrinum* L.) seedlings led to reduced leaf number, nodule number, and plant dry weight. Plant height was initially increased at the two lowest levels of light reduction, but height was reduced as light levels were lowered further. Reduced nodule number was believed due to reduced photosynthate production caused by both reduced light levels and lowered leaf number. Evers also found that delaying the reduced light treatment reduced the effect of lowered light levels. Cooper (1966), in a study to determine the response of birdsfoot trefoil (*Lotus corniculatus* L.) and alfalfa to shading, found that both fresh weight and height were reduced with increased shading, and more so for alfalfa than trefoil. Shading did not affect stand survival. Nodule counts were not reduced in either alfalfa or trefoil until the level of shading had reached 92%.

Cooper (1967) continued work on both species and found that reduced light lowered the net assimilation rate, which in turn reduced the relative growth rate of the plants. In addition, reducing available light or reducing the age at which the plant received reduced levels of light caused a shift in dry matter partitioning from roots to stems. An increase in leaf area ratio with reduced levels of light was due to the an increase in the leaf area to leaf weight ratio and not to an increase in the leaf area to total plant weight ratio. Pritchett and Nelson (1951) also noted that total dry weight and root to shoot dry weight ratio were reduced as light intensity decreased for alfalfa and bromegrass (*Bromus inermus* L.) grown under oats. They also noted that nodulation of alfalfa was reduced at lower light levels and halted altogether at 2765 lux and below. Nodulation resumed when shade was removed, however.

Gist and Mott (1958) found that seedling dry weight of alfalfa, birdsfoot trefoil, and red clover responded in a positive linear manner to increased levels of light. In addition, the ratio of shoot to root growth increased as light levels decreased and as the age at which the seedlings were exposed to the low-light levels decreased in all three species. This response was curvilinear for shoots and linear for roots (Gist and Mott, 1957). All responses were exaggerated as seedling exposure time to reduced levels of light increased.

A study of a pearl millet and groundnut intercropping system found that the intercrop dry matter accumulation was a positive function of the amount of photosynthetically active radiation (PAR) intercepted (Marshal and Willey, 1983). Intercrop dry matter accumulation was intermediate between the results for monocultures of the two component crops.

Klebesadel and Smith (1959, 1960) established alfalfa with an oat intercrop and harvested the oat intercrop when it reached either 30 to 40 cm, boot stage, late milk-early dough stage, or maturity. Light levels began to decrease when the oats reached a height of 13 to 15 cm. Light intensity continued to decrease until the oats reached 50% heading, at which time light intensity increased until grain maturity due to the drying down of the oat leaves. Latter harvest times increased time and intensity of the reduced light period of the alfalfa. Small amounts of alfalfa were harvested (542 to 761 kg ha^{-1}) compared to alfalfa monoculture, and each successive treatment generally reduced the dry matter accumulation. Only the mature oat harvest removal treatment showed a decrease in alfalfa plant density the first year after planting, but there were no differences in the plant densities between treatments for the three year average.

The general trend of these studies is that, as light intensity is reduced, RGR is reduced and remaining growth directed more towards shoots than roots of small-seeded forage legumes. Earlier or longer periods of shading increase the severity of the seedling growth reduction. Nodulation is also detrimentally affected by low light levels. Stand density may or may not be affected by reduced light, depending on the susceptibility of the species or cultivar.

Soil Water Competition: Soil water availability can affect forage legume establishment success under cereal intercrops. Janson and Knight (1973) intercropped alfalfa with wheat, barley, and corn under both irrigated and non-irrigated conditions. Irrigation increased alfalfa forage yields the establishment year. Irrigation also delayed reproductive development, stem elongation, and leaf senescence of the cereal crops, resulting in longer and more intense shading. Shading increased the shoot to root dry matter ratio and left the plants more susceptible to water stress because of smaller root systems. Irrigated intercrops reduced alfalfa yields proportionately more than nonirrigated intercrops. Only the irrigated intercrops reduced plant populations of alfalfa.

Genest and Steppler (1973) found that alfalfa or birdsfoot trefoil which were intercropped with oats, barley, or wheat did not use different amounts of water than the cereal monocultures, but used more water than alfalfa or trefoil monocultures. During establishment, forage yields increased more from greater available water than from greater light penetration.

Klebesadel and Smith (1959, 1960) found that oats, wheat, and rye (*Secale cereale* L.) reduced available soil water for alfalfa and red clover when intercropped. Fall-planted cereals reduced soil water content earlier the following spring than spring-planted cereals.

Under low-light conditions, reduced soil water reduced the growth of roots and shoots of alfalfa, red clover, and birdsfoot trefoil to the same degree (Gist and Mott, 1957). Legume seedlings grown in low light did not respond to moisture level as much as those grown under full-light conditions. Conversely, seedlings grown under low moisture did not respond as greatly to full light as those supplied with adequate moisture. Under levels of adequate moisture, red clover was more shade tolerant than alfalfa, but both responded similarly to shade under water stress. Because root growth and development were decreased when plants were shaded, decreased water stress tolerance resulted, and during periods of drougth plant mortality occurred.

Cooper and Ferguson (1964) also noted reduced root growth of alfalfa, birdsfoot trefoil, and orchardgrass when established with a barley companion crop. Both lateral and vertical root growth were inhibited and root growth ceased after the barley was fully headed. Legume root systems were less able to compete for soil water because they were smaller than those of barley. Forage legume stands were unaffected by the barley companion crop. The year after establishment, root depth of the intercropped legumes was similar to legumes established as monocultures.

These studies suggest that forage yields and shade tolerance may be improved with the use of irrigation. Because root growth, and thus drought tolerance, are reduced in low light environments, irrigation may be required in those situations where severe moisture stress could occur, but could reduce stand density if longer or more intense periods of shading resulted.

Nutrient Competition: Martin and Snaydon (1982) intercropped barley and field beans (*Vicia faba*) in mixed- and alternate-row patterns. All treatments received 70 kg potassium (K) ha^{-1} and 35 kg phosphorus (P) ha^{-1} and either 75 or 90 kg nitrogen (N) ha^{-1}. At barley harvest, there was no difference in the N content of the barley or beans as compared with the monocultures of either crop. It was found that planting pattern had no effect on plant P or K content. Planting ratio (barley:beans) affected plant P and K content, but with no consistent pattern. Land Equivalent Ratios (see Agronomy of Intercropping section for definition) for intercrops were greater than one, with highest yields from alternate-row treatments. The alternate row pattern delayed inter-specific competition between the root systems of the two species by distancing one from another. Alternate-row planted barley did not affect bean growth as greatly as mixed row plantings, but the barley still developed as well as barley monocultures.

When P is applied to red clover, alfalfa, or hairy vetch (*Vicia villosa* Roth.) intercropped with corn, stand survival and legume dry weights were not affected the year of planting (Lefrancois and Scott, 1988). Light and water were thought to be more limiting than P. Residual P increased forage yields in all three species the following year because of soil P depletion during establishment by the corn.

Chamblee (1972) notes that alfalfa grown with perennial forage grasses out-competes the grasses for divalent cations, but may be out-competed for K and sulfur. Alfalfa may be at a competitive disadvantage with grasses for P during establishment before its root system develops deeper than the grass roots.

Intercrop response to fertilization was noted by Oelsligle et al. (1976) for several crops. Nutrient responses varied between cropping systems due to differences in crop requirements. It was suggested that fertilizer be added to intercropping systems to adequately supply plant demands.

Pest Pressure: Increasing species diversity in cropping systems may reduce pest abundance. Risch (1983) reviewed 150 reports and found that in 53% of the cases the abundance of herbivorous pests was lower in intercrops than in monocultures. Pests were less abundant in monoculture 18% of the time. Results were variable in 20% of the cases and showed no effect in 9% of the reports.

Root (1973) suggested that pest numbers in intercrops may be reduced for two reasons. The first reason, the "Enemies Hypothesis", suggests that natural enemies will have more stable and perhaps larger total populations in intercrops because increased plant diversity will provide a more stable supply of prey, hosts, alternate food sources, and more abundant refugia and suitable microhabitats. Russel (1989) reviewed 14 studies designed to test the "enemies hypothesis" and found that in 9 cases the incidence of predation or parasitism was greater in intercrops than in monocultures.

Root's (1973) second reason, the "Resource Concentration Theory", suggests that monocultures of host plants are more attractive to herbivore pests than intercrops of host and non-host plants. The attractiveness of a cropping system is affected by (i) the number of kinds of host plants and the relative pest preference for each, (ii) the absolute density and spatial arrangement of the hosts, and (iii) the interference effects of non-host plants (Risch, 1981). Host plant monocultures maximize attractive stimuli and increase the likelihood of attracting crop pests. Once attracted, the pest will be more likely to come to a field and less likely to leave. Monocultures may also detrimentally affect pest reproductive behavior (Risch, 1981).

Resource concentration may play a larger role in reducing pest numbers in intercrops than the enemies hypothesis (Risch et al., 1983; Bach, 1980). Russel (1989) points out that the enemies hypothesis and the resource concentration hypothesis are not mutually exclusive theories and both undoubtedly play a role in reducing pest numbers in intercrops. There are cases were intercrops have had greater pest infestation than monocultures and each intercropping system should be considered separately.

Agronomy of Intercropping

Yield Criteria: The most important advantage of intercropping compared to monoculture production are increased yields. The most common comparative measure of yields between intercrops and monocultures is the Land Equivalent Ratio (LER). Andrews and Kassam (1976) define LER as the sum of the fractions of the yield of intercrops relative to their sole crop yields. Thus:

$$LER = L_a + L_b = Y_a/S_a + Y_b/S_b$$

where L_a and L_b are the LER's for the individual crops, Y_a and Y_b are the individual intercrop yields and S_a and S_b are the individual monoculture (sole crop) yields (Mead and Willey, 1980). The economic version of the LER is the Income Equivalent Ratio (IER). The IER is calculated the same as the LER, but income is substituted for yield (Andrews and Kassam, 1976).

Willey (1979) defines three intercropping situations which may change the yield requirements of intercrop systems:

> 1) where intercropping must give full yield one crop and some yield of the other ... , 2) where the combined intercrop yield must exceed the highest monoculture yield ... , and 3) where combined intercrop yield must exceed the combined monoculture yields ... .

Establishment of a seed crop with an intercrop applies to the first situation where establishment of the seed crop at full levels is required and any additional profit from the intercrop is a bonus.

Production Practices: Successful crop production using intercropping systems depends on planting pattern and rate, timing of planting and harvesting, incidence of weeds, pests, and diseases, fertilization, and choice of species or cultivar. The best combination of these factors will vary between systems, but careful selection will improve crop production.

Planting Pattern and Rate: Anderson and Metcalf (1957) found that birdsfoot trefoil seed yields were greater when grown with Kentucky bluegrass (*Poa pratensis*), orchardgrass, or timothy (*Phleum pratencse*) than when grown alone. Reducing the seeding rate of the bluegrass by half further increased trefoil seed yields. Reduced seeding rates of timothy and orchardgrass did not change trefoil seed yields. Improved yields were credited to reduced lodging of the trefoil in intercropped treatments.

Alfalfa established alone, with and without herbicides, with an oat intercrop harvested for forage or grain to study alternative establishment methods (Hansen and Krueger, 1973). Alfalfa established with oats for forage produced the greatest dry matter forage yields the first year without affecting second year alfalfa yields. Establishment with oats for grain yielded the least forage. Type of establishment had no effect on crude protein contents of the forage, but forage yields were increased in both years as alfalfa seeding rates were increased.

An experiment in which spring-planted alfalfa was intercropped with Polish rapeseed (*Brassica campestris* L.) found that there was no effect of alfalfa planting pattern (broadcast, 61 cm rows, 15 cm rows with rapeseed) or presence of rapeseed in either parallel or perpendicular rows on alfalfa seed yield the year after establishment (Waddington and Malik, 1987).

Planting in mixed-rows or alternate-rows did not affect seed yields of either soybeans or cowpea intercropped with corn (Allen and Obera, 1983). It was noted that corn was N deficient when intercropped without additional

N fertilizer and that legumes can actually compete with corn for N when intercropped.

Singh et al. (1989) found a higher LER for forage yields of Egyptian clover intercropped with oats than when either crop was planted in monoculture. Broadcast- or cross-sowing of the clover produced higher forage yields after the oat crop was harvested than did alternate-row plantings and were attributed to more uniform land coverage by the clover.

Tossel and Fulkerson (1960) found that reducing oat seeding rates from 90 to 54 kg ha^{-1} tended to increased intercropped alfalfa and red clover stand counts and seedling vigor without lowering oat yields. Spacing oat rows at 18 and 35 cm did not affect stand counts of either alfalfa or red clover. Lower oat seeding rates increased weed competition.

Tesar (1957) found that wider-spaced corn rows improved relay intercropped alfalfa dry matter yields the year after planting because alfalfa seedling survival and size increased as distance from the corn row increased. Alfalfa planted further than 21.6 cm from corn had the best establishment and growth. Wider corn rows increased the number of alfalfa rows further than 21.6 cm from a corn row.

Many studies have been done to determine the effects of planting density and row spacing on the yields of cereal crops. Results of these studies have been very consistent. Guitard et al. (1961) found that wheat, oat, and barley yields remained constant over a wide range of planting densities; 101 to 202 kg ha^{-1} for wheat, 72 to 144 kg ha^{-1} for oats, and 81 to 187 kg ha^{-1} for barley. The plants compensated for lower plant densities by increasing the number of heads per plant, kernels per head, and kernel weight. Joseph et al. (1985) and Darwinkel (1978) found similar results for winter wheat and found increased row spacing (10 to 20 cm) reduced yields at equal planting densities. Reduced yields were the result of fewer heads per area. Fredrick and Marshall (1985) also found that reduced row spacing increased yields as a result of increased fertile tillers per area. Beuerlein and Lafever (1989) found soft red winter wheat yields decreased 8% as seeding rate increased from 167 to 670 seeds m^{-2} and decreased 19% as row width went from 18 to 51 cm. Increased plant densities reduced the number of seeds per head and increased row spacing reduced number of heads per area.

Reduced cereal planting rates may increase the vigor and stand densities of intercropped forages without reducing grain yields, but increasing cereal row width reduces grain yields without benefit to forage intercrops. With some exceptions, planting pattern generally does not affect forage intercrop establishment or yields.

Time of Intercrop Planting: When alfalfa was fall-established with ryegrass (*Lolium perenne* L.) or barley, alfalfa produced greater amounts of dry matter the second year when sown with barley. Ryegrass and barley both competed with alfalfa in the fall and winter, but the ryegrass continued to be highly competitive through the following spring. The barley had a shorter period of competition the following spring and allowed more alfalfa growth. Monoculture establishment of alfalfa with chemical weed control did not improve forage yields, while establishment with an intercrop did provide weed control (Janson, 1975).

Best stands of alfalfa intercropped with corn resulted from planting alfalfa the same day as corn (Pendleton et al., 1957). As alfalfa planting was delayed, alfalfa stands decreased because alfalfa requires the high light period before the corn canopy closes to establish. Delayed planting results in a shorter, but more intense, period of light competition earlier during alfalfa establishment. For later planting dates, lespedeza (*Lespedeza cuneata*) germinated best, followed by alfalfa, sweet clover, red clover, and ladino clover (*T. repens*), in that order (Pendleton et al., 1957). Alfalfa had higher stand counts the second season as corn row width increased.

Fall-planted alfalfa with winter wheat established better than spring-planted alfalfa with spring wheat (Pendleton, 1957). Fall-interplanted alfafa roots reached a depth of 30 cm by the time spring-planted alfalfa would have been sown. Advanced root development was believed to improve the competitive ability of the fall seeded alfalfa, especially during dry springs. Planting before September 21 allowed too much early wheat growth. It was noted that seeding alfalfa in the same row as the wheat (mixed row) reduced winter damage compared with broadcast alfalfa.

Planting time is one of the most critical areas for successful intercrop production. Proper timing results in reduced competitive stress and improved establishment, while poor timing may lead to reduced stands and reduced establishment.

<u>Weeds</u>: Peters (1961) found that oats were more competitive than weeds during the establishment year of alfalfa, red clover, ladino clover, and birdsfoot trefoil. All species except birdsfoot trefoil, which Cooper (1977) ranked as one of the least aggressive forage legume seedlings, had good recovery from the oat competition. Peters noted that weeds were more prevalent in treatments without oat intercrops, however the use of herbicides the year following establishment improved dry matter yields of alfalfa for both with and without intercrop treatments. Establishment with or without an oat

intercrop did not affect alfalfa yields the year after establishment when herbicides were used the second year.

Klebesadel and Smith (1959) found weeds least prevalent in those alfalfa or red clover stands where the intercrop was most competitive for light and moisture. Weeds that develop in alfalfa or birdsfoot trefoil stands as a result of the absence of intercropped cereals caused more intense shading than intercropped cereals (Genest and Steppler, 1973).

Schmid and Behrens (1972) found that an oat companion crop for grain and straw was more profitable than using herbicides (2,4-DB + EPTC) for the establishment of alfalfa and did not affect future alfalfa yields. In another study, applications of 2,4-DB and Diclofop reduced annual grassy and broadleaf weed numbers more than a barley companion crop did in establishing stands of alfalfa (Moyer, 1985). However, the combined forage yield of the barley and alfalfa was similar to the yield of the alfalfa + herbicides treatment the planting year. Intercropping and chemical weed control were only practiced the seeding year. Second year intercropped alfalfa yields were 84% of the chemically controlled alfalfa, but the yields for both treatments were the same in years three and four. Moyer did not perform an economic analysis of the two production methods, but noted that the best method depended on cost of establishment as well as yields.

Establishment of forage crops with cereal intercrops reduces weed competition. If good weed control practices are implemented prior to intercropping and normal weed control measures are taken after the cereal crop is harvested, weeds should not adversly affect forage or seed crop production.

Fertilization: Snap beans planted under corn did better than soybeans, although LER showed little difference between the two systems (Cordero and McCollum, 1979). As N application rates increased from 0 to 252 kg ha^{-1}, corn leaf area duration increased which increased the duration, or intesity, or both, of shading to the soybean and decreased soybean yields. Application of N did not affect snap bean yields.

Reinbott et al. (1987) found that soybeans relay-intercropped with wheat had reduced yields when N was applied in amounts higher than 56 kg ha^{-1}. The higher rates of N increased wheat vegetative growth resulted in lowered light availability to the soybeans. Intercropped soybeans yielded more when planted in 20 rather than 80 cm rows. Soybean yields also increased as planting was delayed because the period of competition between the two crops was decreased.

When intercropping, care should be taken that excess N fertilization does not occur. Resultant luxury growth adversly affects lower story plants by increasing shading intensity and duration.

Species and Cultivar Effects: Waddington and Bittman (1983, 1984a, 1984b) established alfalfa with wheat, Argentine rapeseed (*Brassica napus* L.) and Polish rapeseed. Wheat lowered alfalfa yield the seeding and second year, but lowered the weed incidence some of the time. Yields were not affected in the third and fourth years. Both rapeseed species reduced alfalfa dry matter production the first two years after seeding and also reduced the incidence of weeds. Earlier planting dates of both rapeseed species tended to improve alfalfa yields. Severe problems with volunteer rapeseed and the inability to effectively control it made wheat the better species to use during alfalfa establishment.

A study comparing the establishment of alfalfa with either oats or barley found that yield was increased with no adverse affect on forage quality. Barley provided higher quality forage as a companion crop than did oats, but was more competitive with alfalfa than oats (Brink and Marten, 1986). Kust (1968) found that alfalfa established with oats yielded more than alfalfa established alone, either with or without herbicides. In addition to increased forage yield, the oat crop protected the alfalfa from winter cold damage. Combined yields were highest when oats were harvested at the boot stage.

Several studies have been conducted to improve bean yields of corn-bean intercrops by determining optimum growth habits for both. Davis et al. (1984) generally found that there was no difference between bush and climbing bean yields when intercropped with corn, even though climbing beans out yielded bush beans when staked in monoculture. Clark and Francis (1985) similarly found that the relative yield decrease was greater for climbing beans than for bush beans when intercropped with corn. They concluded that climbing beans in monoculture continued to increase leaf area and filled pods longer than bush beans, but when intercropped, increased corn competition later in the season made time of leaf establishment and pod fill similar between the two bean growth habits. They suggested that beans for intercropping be bred for high yields during the time of reduced corn competition (early season) rather maximum yield in monoculture.

Woolley and Rodríguez (1987) studied the effects of corn growth habit on corn-bean intercrops and found that taller corn cultivars tended to shade less than shorter cultivars, but that taller, leafier cultivars affected beans the same as shorter, less leafy plants. Leafy-type corn provided more weed control than did less leafy types, but less leafy types improved bean yields for both companion- and relay-intercropped beans. Short-leafy corn types yielded the most, but were the most detrimental to bean yields when intercropped. Since LER's for corn-bean intercrops are higher than those for corn or bean monocultures, breeding corn types which maximize intercrop yields, instead of corn yields, may be more useful for intercropping systems.

These corn and bean intercropping studies illustrate that cultivars adapted for intercropping are needed for intercropping systems. Francis et al. (1976) cite several plant characteristics which would be useful to breed into intercrops. These include photoperiod insensitivity to allow planting date flexibility, early maturity to reduce period of intercrop competition, and short, non-lodging types which respond to nitrogen without increased foliage production.

ESTABLISHMENT OF KURA CLOVER FOR SEED WITH WHEAT INTERCROPS

Abstract

Kura clover (*Trifolium ambiguum* M. Bieb.) is slow to establish and has low seed yields the year after establishment. Intercropping a cereal grain during clover seed field establishment could provide additional revenue to seed growers, provided that intercropping did not jeopardize future clover seed yields. Factorial combinations of spring- and fall-planted kura clover monocultured, companion-intercropped with wheat (*Triticum aestivum* L.) at two row widths, and relay-intercropped with wheat at two row widths were compared. Spring-planted clover established better than fall-planted clover as measured by percent ground cover. Both spring- and fall-planted kura clover were better established when relay-intercropped than when companion-intercropped. Spring-planted kura clover relay-intercropped with fall wheat established better than any other treatment combinations, comparing favorably with spring-planted kura clover monocultures at 18 months from planting. Kura clover generally did not affect wheat yields. Wide and narrow row spaced wheat generally affected kura clover similarly, with narrow-spaced wheat out yielding wide-spaced wheat. It was concluded that relay-intercropping fall wheat into spring-planted clover does not adversely affect clover establishment and could therefore provide more cash revenue than monocultured clover during the clover establishment period.

Introduction

Kura clover is a long-lived, rhizomatous species which has good disease, drought, water logging, and cold resistance (Bryant, 1974) and is highly nutritious to livestock (Allinson et al., 1985). Interest in this species as a pasture and soil conservation crop is increasing, but limited seed supplies will hamper its widespread use (Speer and Allinson, 1985).

Kura clover has slow seedling growth and a long establishment period (Speer and Allinson, 1985). Because of slow growth, and perhaps other reasons, seed yields the first year after planting are as low as 78.1 kg ha^{-1}, although seed yields in later years are as high as 508.7 kg ha^{-1} (U.S. Dept. Ag., Soil Conservation Service, 1989). A long establishment period with low economic returns could discourage potential seed grower interest in this species. Intercropping with a cash crop during the establishment year before full seed production potential is reached offers an economic incentive to establish kura clover for seed production.

Intercropping usually produces interspecific competition between the component crop species for factors such as light, water, and nutrients. Proper planting time, pattern, and choice of species or cultivar can reduce the effects of competition by delaying or reducing competitive stresses. Pendleton (1957) found that alfalfa (*Medicago sativa* L.) companion-intercropped with wheat was established better when planted in the fall than spring because the fall-planted alfalfa established a root system better able to compete with wheat the following spring, when moisture could be limiting. A wide row-spaced corn (*Zea mays*) planting pattern improved the establishment of alfalfa when the two species where relay-intercropped (Tesar, 1957). Wider corn row spacing resulted in larger alfalfa seedlings, better survival, and improved alfalfa dry matter yields the year after establishment than narrow spacing. Wooley and Rodríguez (1987) found that taller, less leafy corn cultivars shaded intercropped beans less than short leafy cultivars, even though short leafy corn yielded most when monocultured. The best corn cultivars for intercropping with beans were tall and less leafy. Some examples of intercropped seed production include oats and red clover seed; wheat and subterranium clover seed (Gomm et al., 1976); and wheat and orchardgrass or red fescue (Chastain and Grabe, 1988 and 1989). No research has been conducted on kura clover and wheat intercropping systems although it may offer advantages to monoculture establishment of kura clover for seed.

This experiment uses wheat as the intercrop because of its potential economic returns and ease of management as an intercrop. While intercropped wheat can provide good revenue, to be useful it should not interfere with kura clover establishment and later seed yield. Thus spring- and fall-planted kura clover monocultures were compared with clover companion- or relay-intercropped with wheat at narrow and wide row spacings to determine the best balance between wheat production and kura clover establishment.

Materials and Methods

Research plots were established at the Schmidt Research Farm of Oregon State University, near Corvallis, OR on Woodburn silt loam (fine-silty, mixed, mesic Aquultic Argixeroll). Kura clover, cv. Rhizo, was either planted alone (monocultured), planted with wheat (companion-intercropped) in narrow and wide rows, or planted and then over-seeded with wheat in narrow and wide rows the following planting season (relay-intercropped). Kura clover was spring-planted 28 April 1989 and 19 April 1990 and fall-planted 19 Oct. 1989. 'Westbred 906R' spring wheat was planted 28 April 1989 (companion-intercropped) and 19 April 1990 (companion- and relay-intercropped) and 'Hill 81' fall wheat was planted 19 Oct. 1989 (companion- and relay-intercropped) and 17 Oct. 1990 (relay-intercropped) (Fig. 1).

Prior to planting, the plot area was fumigated with methyl bromide. Treatments were arranged in a randomized complete block design with four replications, each plot being 2.51 by 7.54 m in size. The plot area was chisel-plowed to a depth of 26 cm, disced, and harrowed to prepare a wheat seedbed. If companion-cropping, wheat was then planted with a standard grain drill in 15- and 30-cm rows, the plots ring-rolled to prepare a firm clover seedbed, and the clover planted to a depth of 5 mm in 30-cm rows with a standard grain drill. If relay-intercropping, the plots were ring rolled and the kura clover planted to a 5 mm depth in 30-cm rows with a standard grain drill, and the following planting season wheat was planted into the clover with a John Deere 'no-till' drill in 20- and 40-cm rows without further field preparation. The clover seed was inoculated with *Rhizobium spp.* suitable for kura clover (Trifolium Spec. #3, Nitragin Co.). Wide- and narrow-spaced wheat monoculture controls were planted at the same time as the

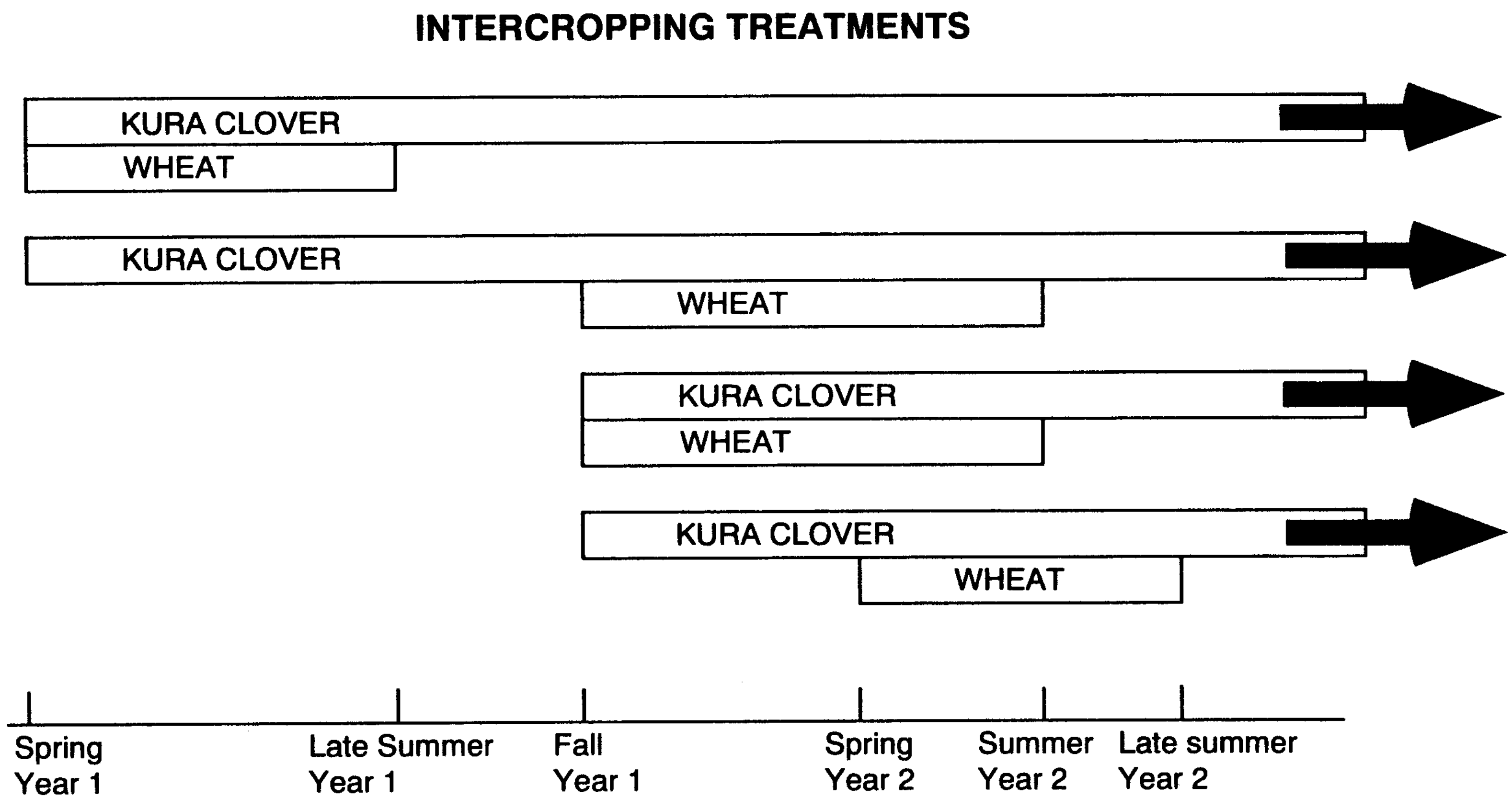

Figure 1. Generalized pattern of planting and harvest times. Year 1 is 1989 and year 2 is 1990. A second series was started for spring planted clover in 1990.

companion- and relay-intercropped wheat treatments. Wheat and clover were planted perpendicular to one another, with wheat planted along the length of the plots (north to south).

Kura clover was planted at a rate of 9 kg ha^{-1}. Spring-planted wheat was seeded at a rate of 140 kg ha^{-1}, fall-planted wheat was seeded at a rate of 117 kg ha^{-1}. Spring-planted wheat received 112 kg ha^{-1} of urea nitrogen at planting and 56 kg ha^{-1} prior to anthesis. Fall-planted wheat received 56 kg ha^{-1} of urea nitrogen at planting and 112 kg ha^{-1} prior to anthesis. Plots were sprinkle-irrigated as needed to maintain a moist seedbed during the first spring and summer after planting.

Attacks by western spotted cucumber beetle (*Diabrotica undecimpunctata undecimpunctata*) on kura clover were controlled with malathion during the spring of 1989. One hive of honey bees was placed near the 1989 spring-planted kura clover plots during the clover flowering period of 1990 for use as pollinators.

Photosynthetic photon flux density (PPFD) (μmol m^{-2} s^{-1}) was measured with a Line Quantum Sensor and Data Logger (Li-cor Co., Lincoln, NE). PPFD was measured at the top of the wheat canopy and the top of the kura clover under-canopy. The sensor was positioned perpendicular to the wheat rows in both cases. Light data was collected only on clear, sunny days, within 2 hours of noon.

The number of trifoliate leaves per clover plant were counted at varying intervals throughout the experiment, using the scale proposed by Carlson (1966). Clover plant density counts taken, until the clover plants grew together or started rhizomatous growth. After that time, only the percent of ground covered by kura clover (% clover) was measured, to the nearest 5 percent, using 20-cm x 50-cm frames. Whole-plant clover samples were taken immediately after wheat harvest for above- and below-ground dry phytomass and leaf area measurements, except for spring-planted relay-intercropped clover, which had grown together, making plants indistiguishable.

Spring-planted wheat was harvested 17 Aug. 1989 and 9 Aug. 1990. Fall-planted wheat was harvested 17 July 1990. Wheat was harvested with a Hege (Hans-Ulrich Hege, Waldenburg/Woertt, West Germany) plot combine. Wheat stubble heights were between 15 and 20 cm, and the wheat straw was removed by hand after the harvest.

The 1989 spring-planted kura clover monocultures and 1989 spring-planted kura clover which had been companion-intercropped with wheat were harvested 23 July 1990 with a 1 m wide power sickle-bar mower, the plant material bagged and oven dried and weighed. The plant material was then belt-threshed twice, put through an air-screen seed cleaner, aspirated, weighed, and harvest index (Donald, 1962) determined. Spring-planted kura clover which had been relay-intercropped with wheat could not be harvested for seed yield because the prior wheat harvest had removed all seed heads.

All variables were tested by analysis of variance. All differences reported are significant at $P \leq 0.05$ unless otherwise indicated.

Results and Discussion

Light Competition: Companion- and relay-intercropped wheat reduced the amount of light available to the kura clover under-canopy (Fig. 2, 3, and 4). Shading reduced the population density, leaf number, plant dry weight, leaf area, and percent ground cover of companion- and relay-intercropped clover. The most intense shading was caused by fall companion-intercropped wheat (Fig. 3), which severely lodged in most plots, and reduced the amount of light reaching the clover under-canopy to as little as 1% of full sunlight. Wide-spaced wheat did not necessarily increase the amount of light available to the clover plants below. Light availability increased beneath 1989 fall-planted relay-intercropped wheat (Fig. 2) and fall-planted companion- and spring-planted relay-intercropped wheat (Fig. 3) as the wheat crop dried down and leaves began to senesce, as also noted by Klebesadel and Smith (1959, 1960) in oats with alfalfa. Because small grain crops like wheat tiller in response to lower plant densities and in large part compensate for lower plant densities (Guitard et al., 1961), wheat planting rates would probably have to be lowered below the level of adequate economic return to significantly increase the amount of light available to the lower-canopy clover.

Timing of the intercrop competition period can be important in reducing the effect of shading on the lower-canopy crop (Pendleton et al., 1957; Pendleton, 1957). Winter-shading by fall-planted companion- or relay-intercropped wheat will coincide with the period of kura clover winter dormancy, although spring-shading by fall-planted companion-intercropped wheat caused the greatest light reduction to the under-canopy clover. Also, a fall-planted wheat crop will be harvested earlier than a spring-planted

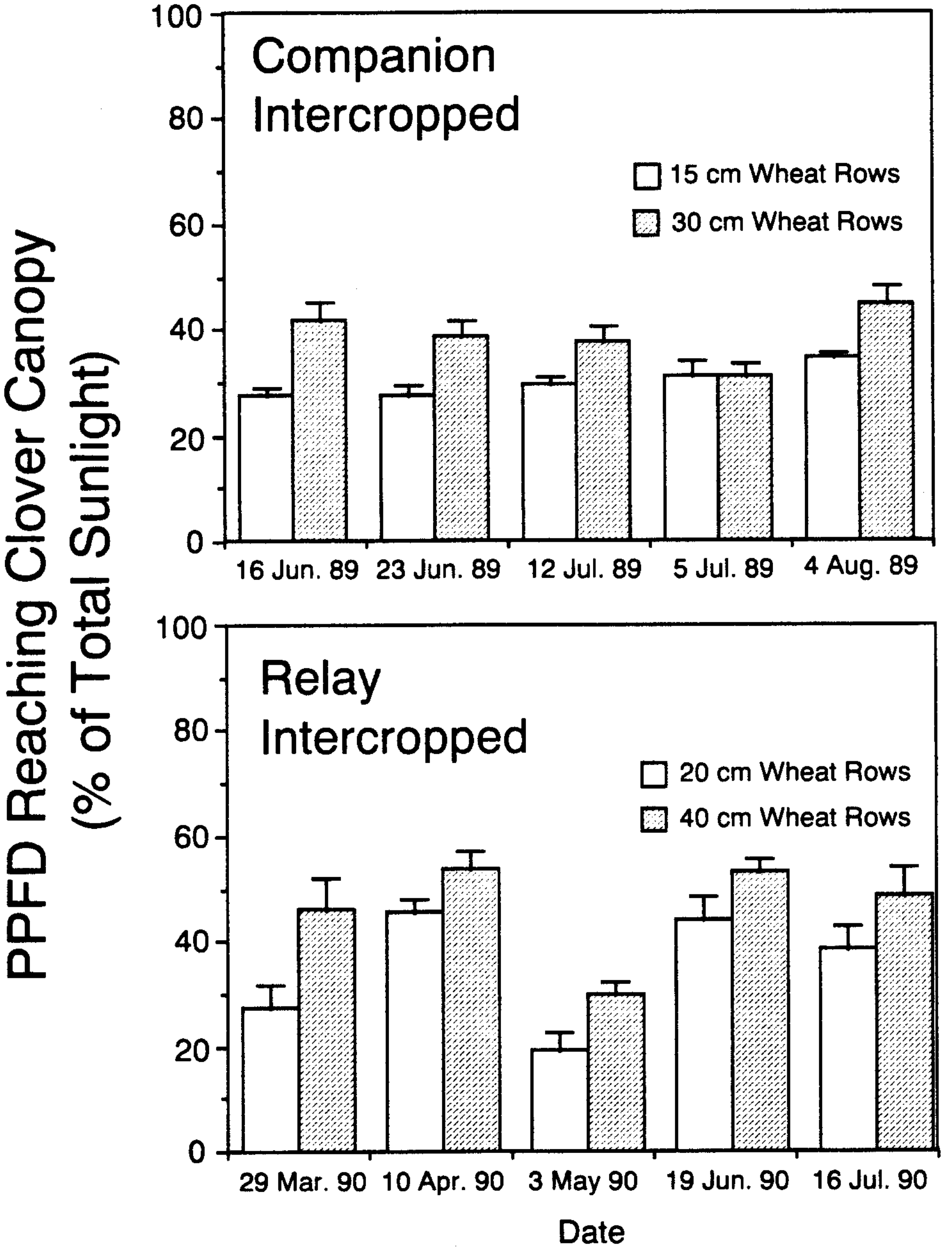

Figure 2. Percent of total PPFD reaching 1989 spring-planted kura clover through companion- and relay-intercropped wheat canopies. Vertical bars indicate standard error of the mean.

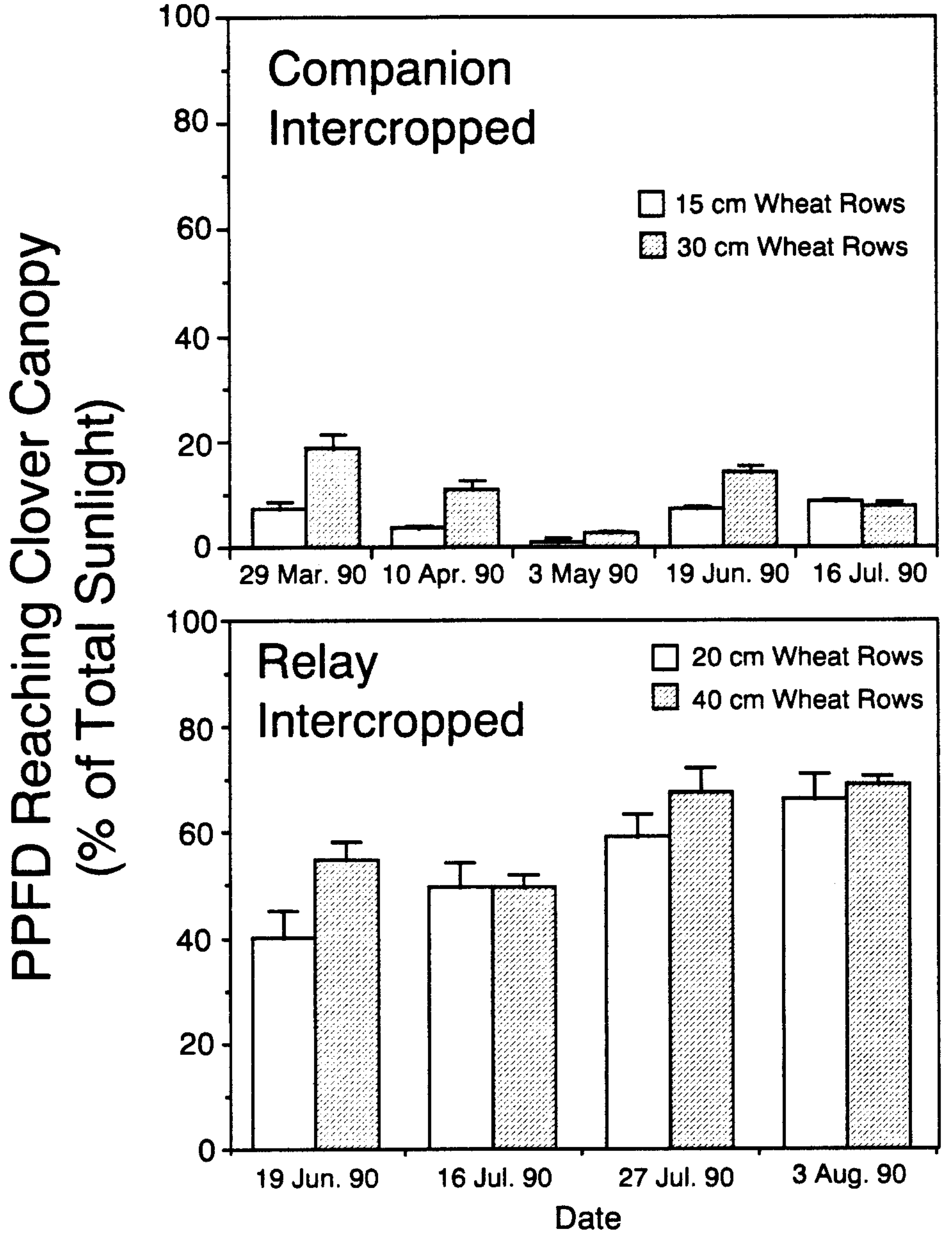

Figure 3. Percent of total PPFD reaching 1989 fall-planted kura clover through companion- and relay-intercropped wheat canopies. Vertical bars indicate standard error of the mean.

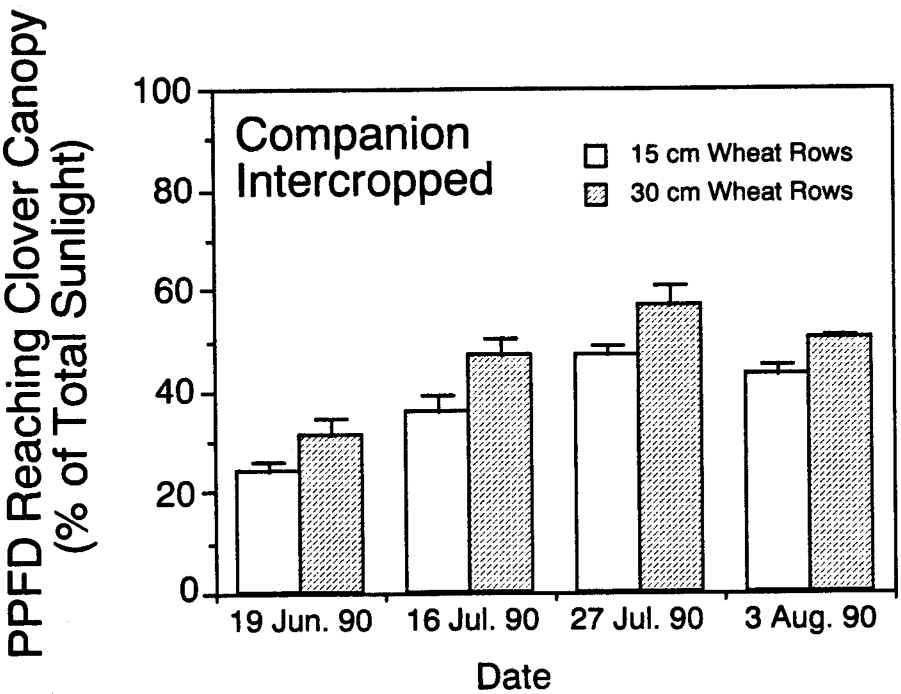

Figure 4. Percent of total PPFD reaching 1990 spring-planted kura clover through companion-intercropped wheat canopy. Vertical bars indicate standard error of the mean.

wheat crop, thus allowing for more time for the clover to recover after wheat light competition is removed. Janson (1975) previously showed that earlier removal of an intercrop improved alfalfa growth the summer after fall establishment.

Kura Clover Population Density: Initial clover plant density after germination was 200 to 250 plants m^{-2} for all intercropping treatments and monocultures (Fig. 5, 6, and 7). Monocultured clover plant populations may decrease after planting due to mortality from intraspecific competition, winter damage, insect herbivory, or other factors. Companion- and relay-intercropping resulted in reduced clover plant densities compared to monocultured treatments. Fall-planted companion-intercropped clover populations were completely killed due to winter damage and intense shading after the wheat had lodged the summer after planting (Fig. 6). Narrow-row spaced wheat lowered plant densities of 1989 fall-planted relay-intercropped clover (Fig. 6) and the 1990 spring-planted companion-intercropped clover (Fig. 7) more than wide-row spaced wheat.

The 1989 spring-planted companion-intercropped clover was selectively attacked immediately after germination by western spotted cucumber beetle. Reasons for the selective attack are not fully understood, but the added cover afforded by the companion-intercropped wheat may have played a role in attracting beetles. Fall 1989 and spring 1990 clover plantings were not attacked in large numbers, possibly because older clover plantings attracted the beetle populations away from new seedlings. Larger clover plants were not affected by beetle damage. The beetle attack resulted in much lower 1989 spring-planted companion-intercropped clover plant densities prior to the period of intense wheat competition than

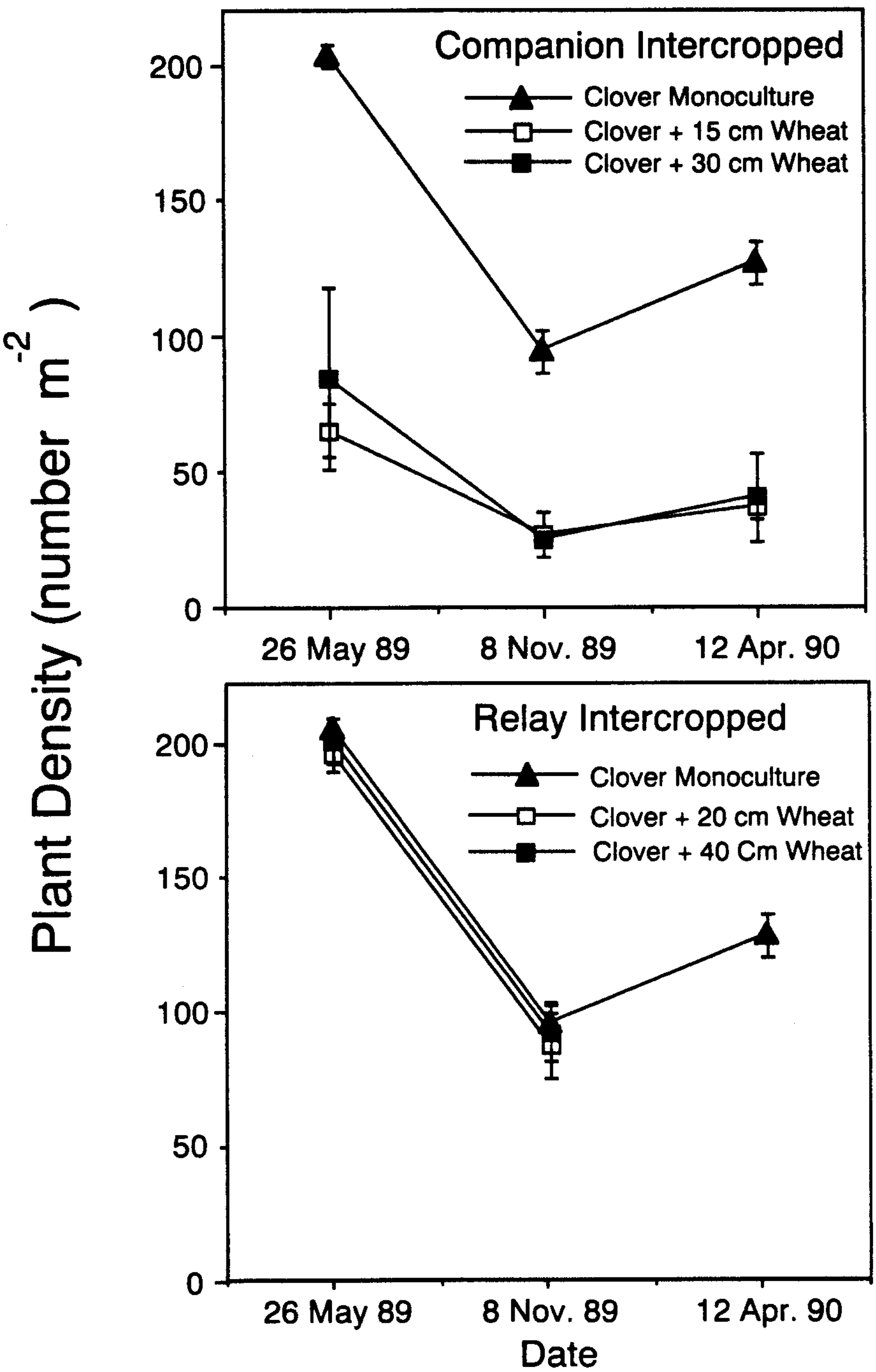

Figure 5. Population density of 1989 spring-planted kura clover with companion- and relay-intercropped wheat. Vertical bars indicate standard error of the mean.

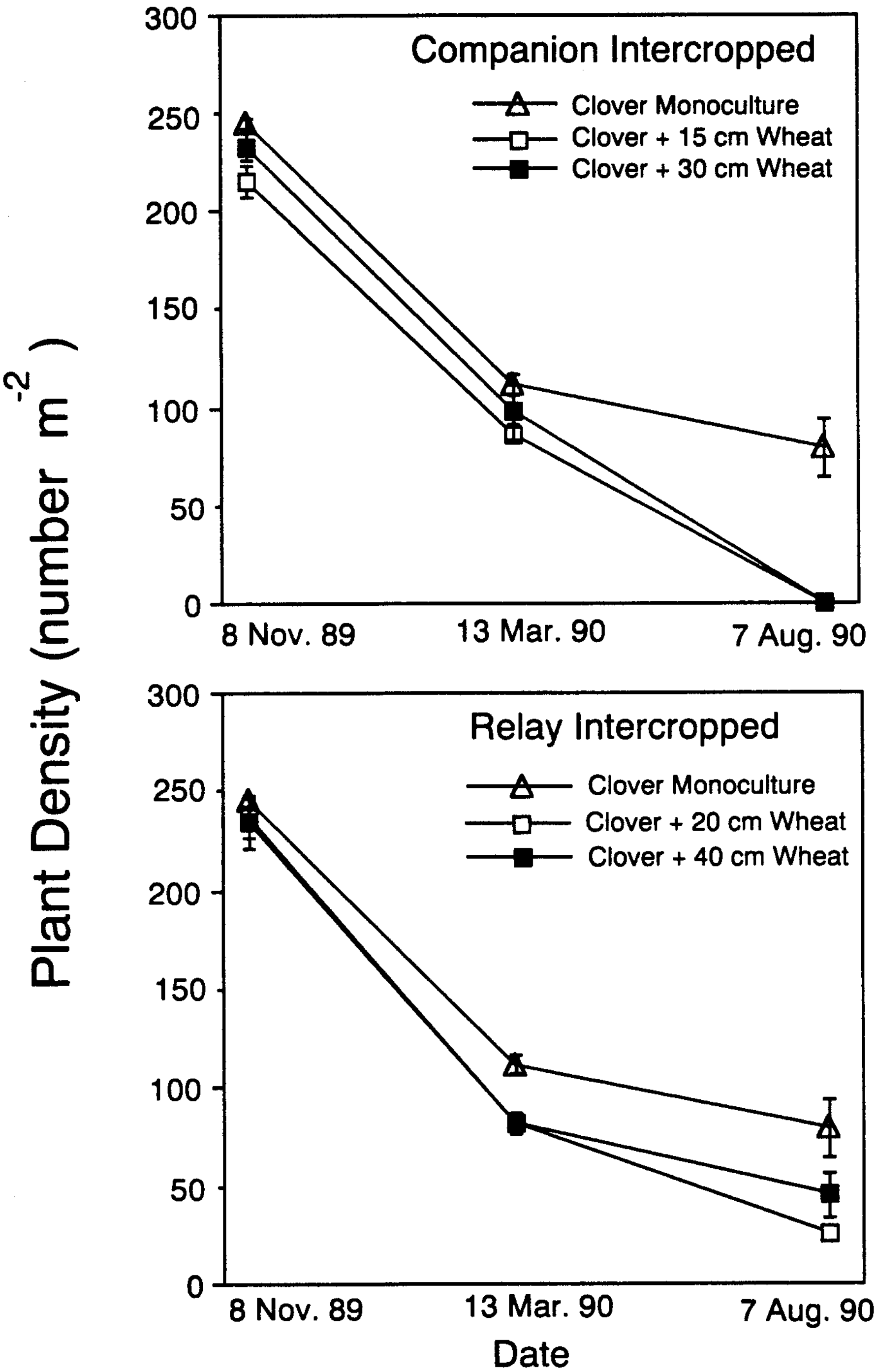

Figure 6. Population density of 1989 fall-planted kura clover with companion- and relay-intercropped wheat. Vertical bars indicate standard error of the mean.

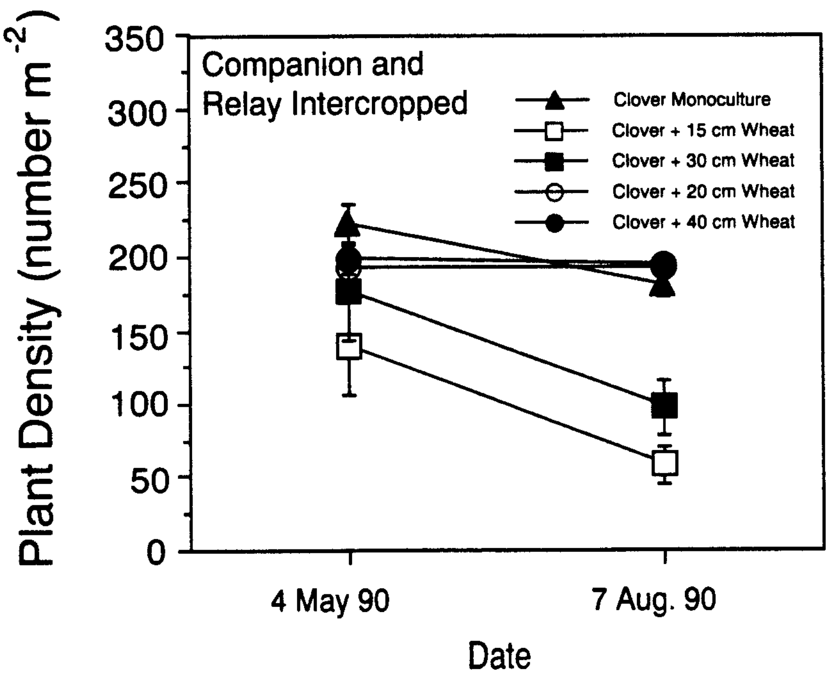

Figure 7. Population density of 1990 spring-planted kura clover with companion- (15 and 30 cm) and relay- (20 and 40 cm) intercropped wheat. Monoculture and relay-intercropped values are not different because the relay-intercropped wheat had not yet been planted. Vertical bars indicate standard error of the mean.

monoculture and relay-intercrop treatments (Fig. 5), confounding the effects of intercropping on plant density. Because kura clover is rhizomatous, it can compensate for population loss by spreading vegetatively. While the losses of the 1989 beetle-damaged spring-planted companion-intercropped clover are probably too great for this to happen, the 1990 spring-planted companion-intercropped clover appears to be overcoming the population losses (Fig. 7) from interspecific competition.

Increases of 1989 spring-planted clover density during the spring of 1990 were due to rhizomatous growth. The effects of relay-intercropping on population density of spring-planted clover were not determined because rhizomatous growth made individual plants indistinguishable. Regrowth of spring-planted clover after fall relay-intercropping indicates that any clover plant mortality from wheat competition occured only at low levels, if at all.

Kura Clover Growth and Establishment: Plant leaf number was used to determine clover development from germination until individual plants became indistinguishable. There was no difference in clover leaf number per plant between monocultured, companion-, or relay-intercropped clover, for either spring- (Fig. 8 and 10) or fall-planted (Fig. 9) clover immediately after the wheat was planted. However, reduced leaf numbers were found by the end of the companion- or relay-intercropping periods. Evers (1989) also found reduced leaf numbers of *T. alexandrinum* after shading. This lag time effect represents the amount of time required for wheat to cause significant shading of the clover and for plant reserves which support leaf maintenance to be depleted. After shading and reserve depletion, leaf growth slowed or stopped and leaf senescence occured, resulting in fewer total leaves with time. Shading was so severe in the fall-planted companion-intercropped

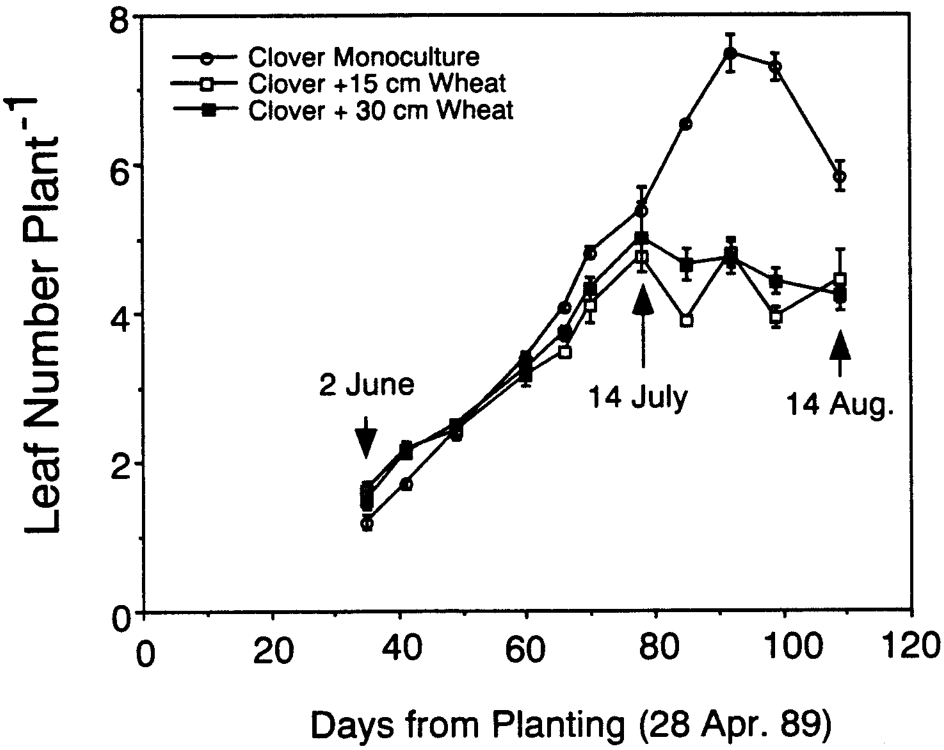

Figure 8. Leaf number of 1989 spring-planted kura clover with companion-intercropped wheat. Vertical bars indicate standard error of the mean.

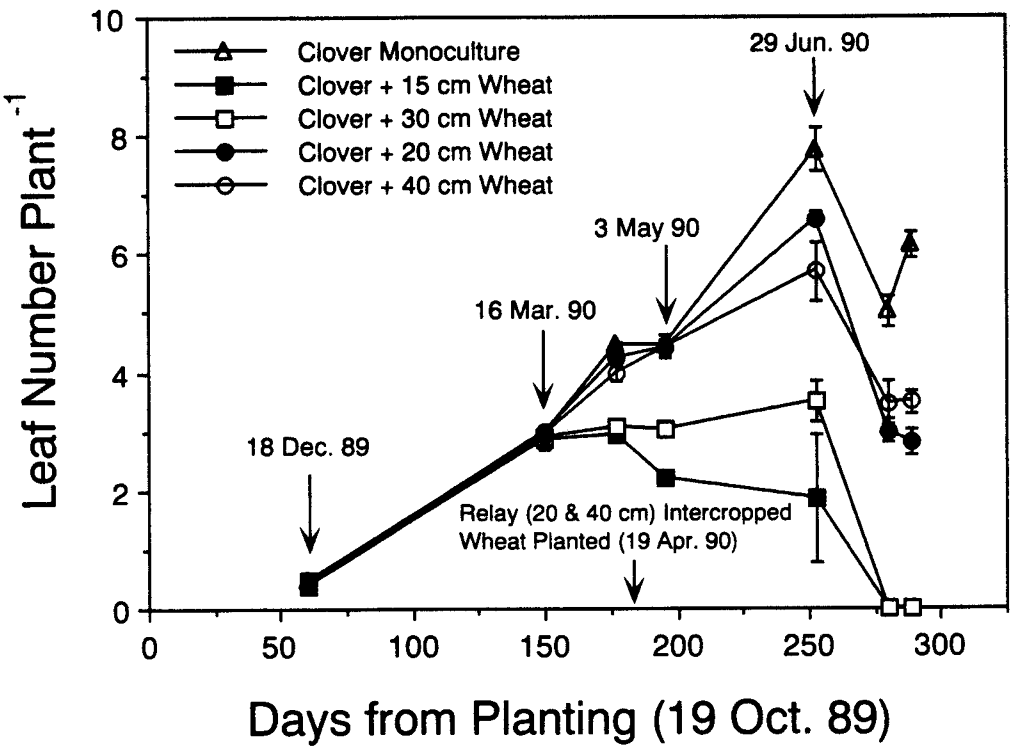

Figure 9. Leaf number of 1989 fall-planted kura clover with companion- (15 and 30 cm) and relay- (20 and 40 cm) intercropped wheat. Vertical bars indicate standard error of the mean.

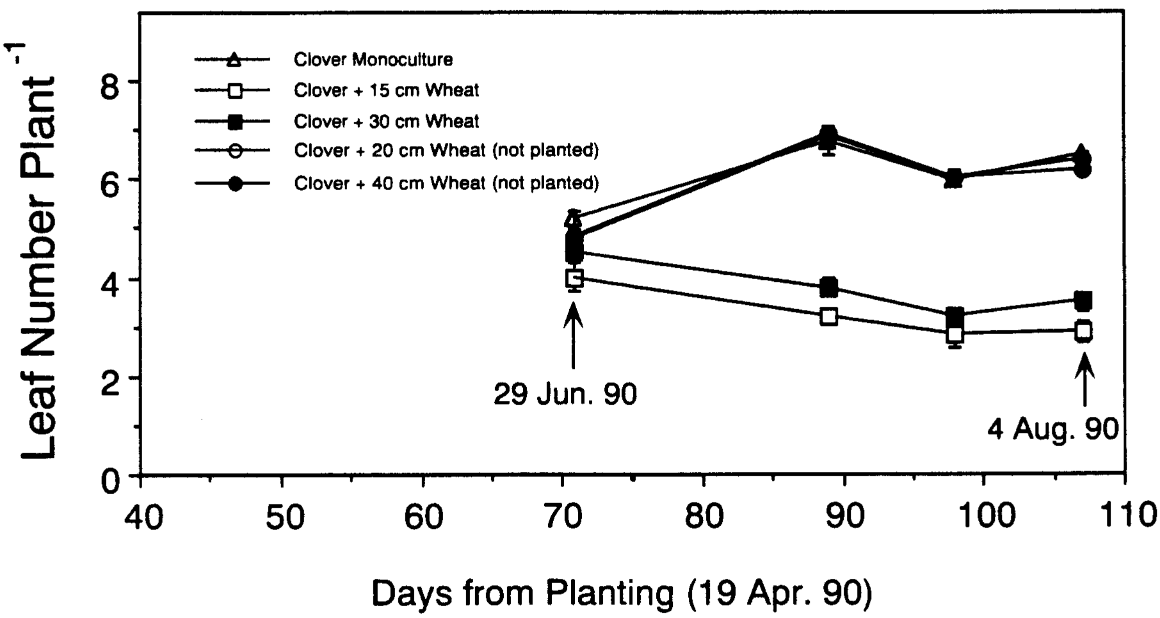

Figure 10. Leaf number of 1990 spring-planted kura clover with companion- (15 and 30 cm) and relay- (20 and 40 cm) intercropped wheat. Monoculture and relay-intercropped values are not different because the relay-intercropped wheat had not yet been planted. Vertical bars indicate standard error of the mean.

clover that complete clover mortality resulted (Fig. 9). Relay-intercropped wheat had less effect than companion-intercropped wheat on the clover leaf growth (Fig. 9). After leaf number decline began, clover planted with wide-spaced wheat generally had more leaves per plant than clover planted with narrow-spaced wheat (Fig. 8, 9, and 10).

Late-season leaf number decline of monocultured clover (Figures 8 and 9) was due to loss of juvenile leaves and slow replacement with larger mature leaves. Large-mature leaves were not noted as frequently in the companion-intercropped or relay-intercropped treatments. Large-mature leaves are seldom seen until eight to ten small, juvenile leaves have been produced. The start of large leaf production may signal the end of the juvenile period for kura clover, which is characterized by small round leaves and short petioles.

After companion- or relay-intercropped wheat harvest, clover root and shoot dry weights (Fig. 11) and leaf areas (Fig. 12) were lower than monocultured plants. Evers (1989) had previously found that dry weight of *T. alexandrinum* was reduced after shading. Additionally, the root to shoot ratio of kura clover decreased after companion- or relay-intercropping, but roots still weighed more than shoots. Reduced root to shoot dry weight ratios and total dry weights of intercropped alfalfa or birdsfoot trefoil (*Lotus corniculatus* L.) have also been noted (Pritchett and Nelson, 1951; Cooper, 1967). Monocultured and relay-intercropped treatments of spring-planted clover were the same for root and shoot weights and leaf areas because the relay-intercropped treatments had not been planted at plant sampling time. Samples could not be taken for the spring-planted clover with relay-

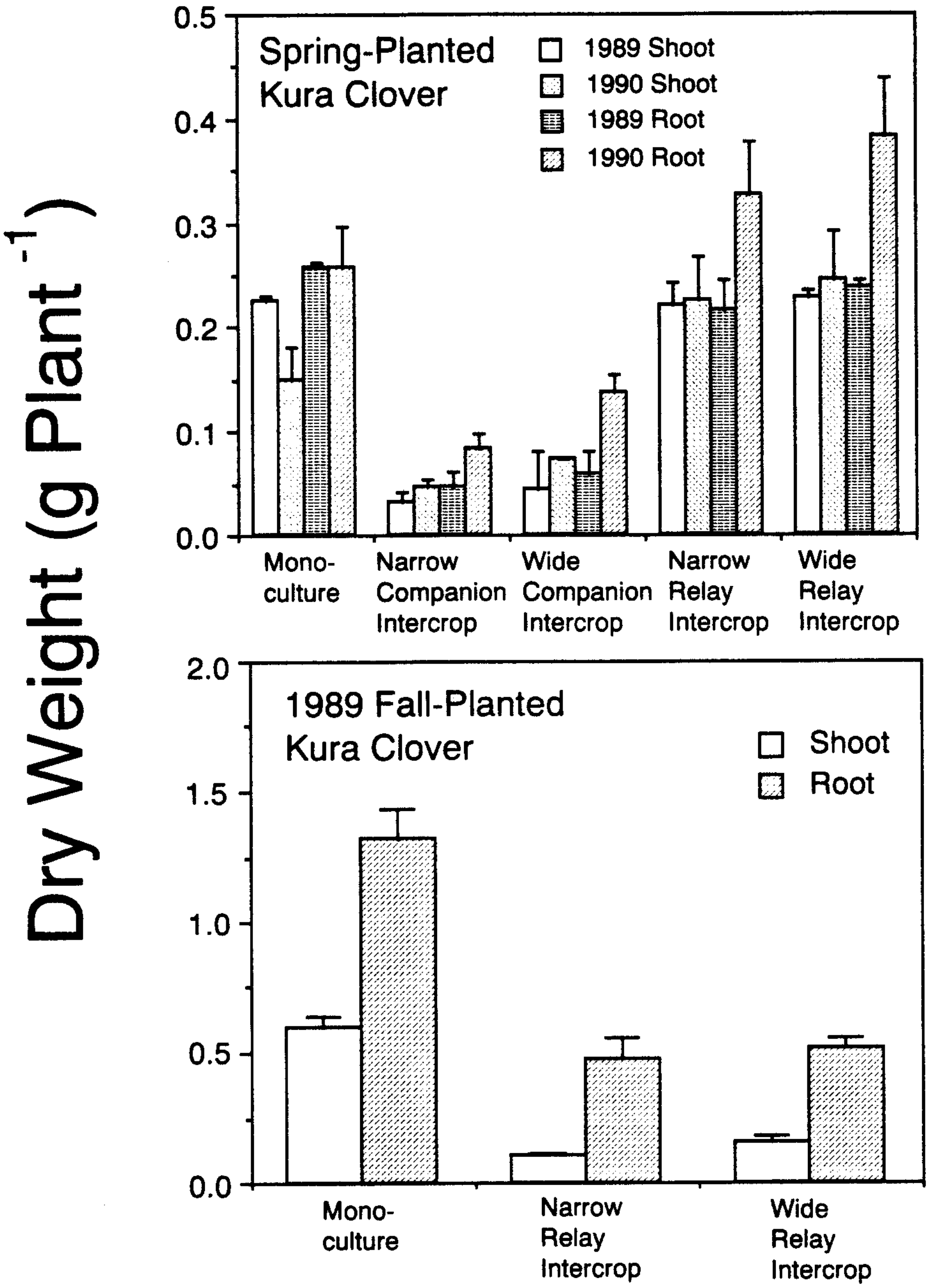

Figure 11. 1989 and 1990 shoot and root dry weights per plant. Spring-planted monoculture and relay-intercrop values are similiar because relay-intercropped wheat had not been planted at sampling time. Fall-planted companion-intercropped kura clover stands had complete mortality. All samples taken after spring wheat harvests. Vertical bars indicate standard error of the mean.

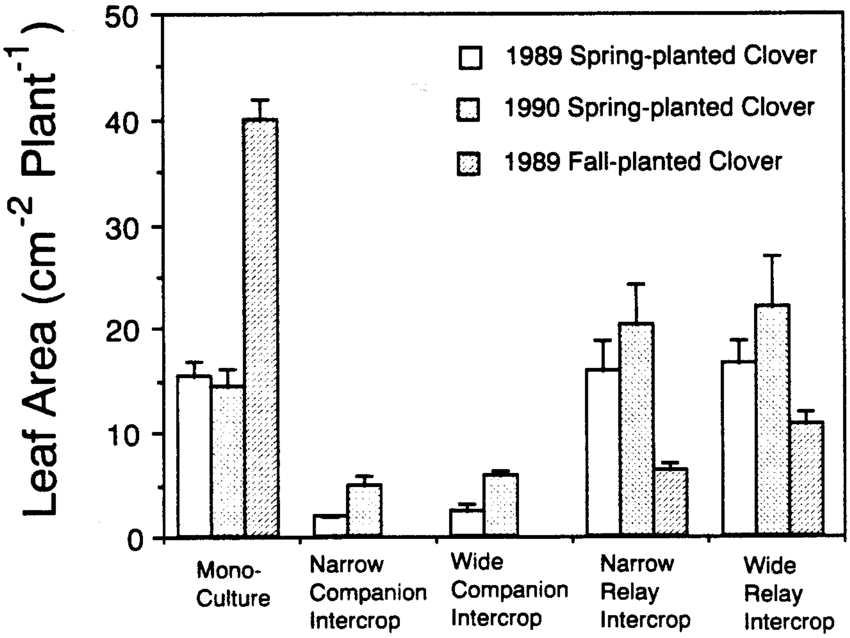

Figure 12. Kura clover leaf area per plant. Samples taken after spring wheat harvests. Spring relay-intercrop leaf areas are similiar to monoculture because relay-intercropped wheat had not yet been planted. Fall-planted companion-intercropped clover values are not shown due to complete stand loss. Vertical bars indicate standard error of the mean.

intercropped wheat because the plants had grown together or for the fall companion-intercropped clover due to complete loss of stand.

The amount of soil surface covered by kura clover plants (% cover) was used as the primary measure of clover stand establishment. The 1989 monocultured fall-planted clover failed to reach 25% cover by the fall of 1990, while the fall-planted companion-intercropped clover died out completely and the relay-intercropped clover covered only 10% to 15% of the soil surface (Fig. 14). By comparison, both the monocultured and relay-intercropped 1989 spring clover had reached essentially 100% cover by the fall of 1990 (Fig. 13). The 1989 spring-planted companion-intercropped clover treatments had still not recovered from the previous spring's beetle damage.

By the fall of 1990, the spring 1990 monocultured clover and the clover companion-intercropped with wide-spaced wheat had similar % cover and greater % cover than clover companion-intercropped with narrow-spaced wheat (Fig. 15).

<u>Clover Harvest</u>: Seed was harvested in the summer of 1990 from 1989 spring-planted monocultured and companion-intercropped clover (Table 1). Relay-intercropped clover was not harvested because the previous wheat harvest had removed all seed heads. Monocultured treatments produced more seed and above ground phytomass than companion-intercropped treatments. However, the clover crop harvest index did not differ between monocultured and intercropped treatments. Differences in 1990 seed yield and above ground phytomass were due mainly to initial seedling stand loss by cucumber beetle attack. The lack of difference in harvest index indicates that the companion-intercropped clover

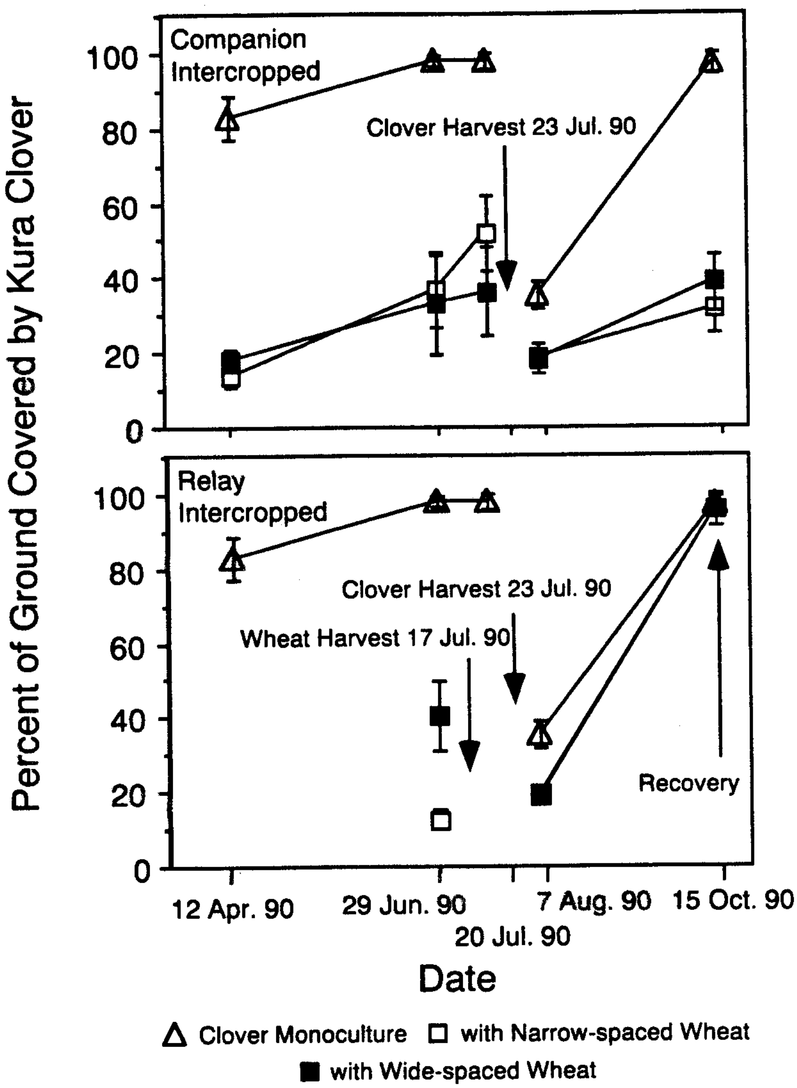

Figure 13. Percent of the ground covered by 1989 spring-planted companion- and relay-intercropped kura clover. Companion-intercropped wheat harvested in the summer of 1989. Vertical bars indicate standard error of the mean.

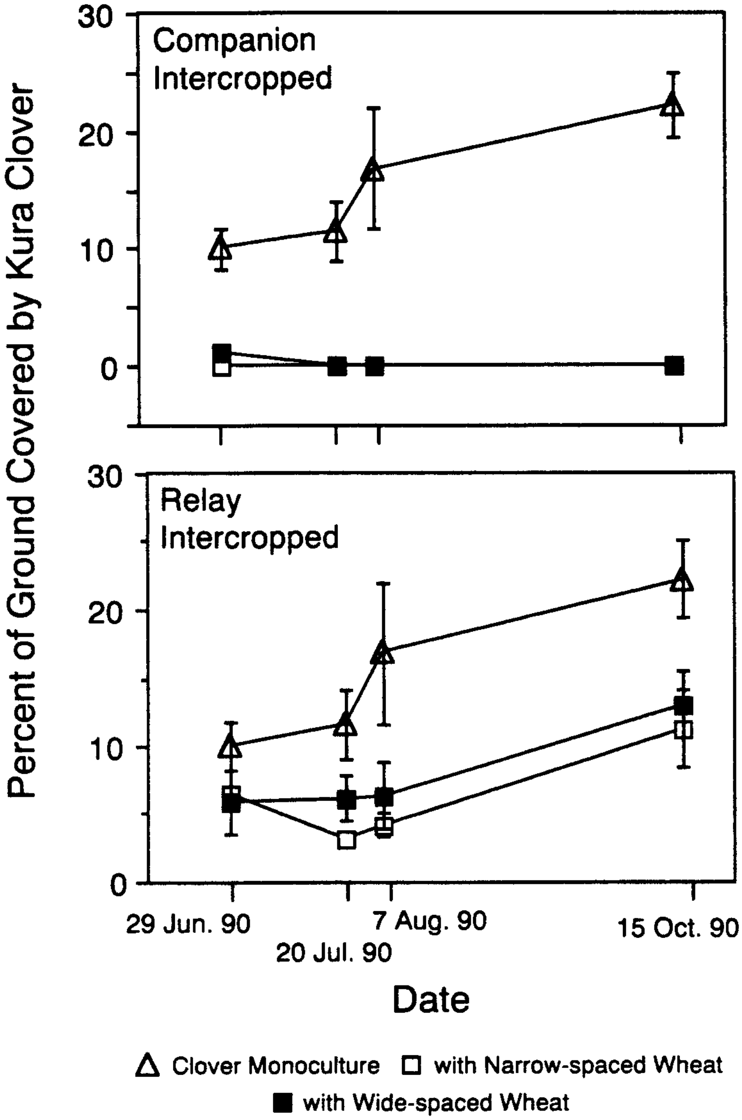

Figure 14. Percent of the ground covered by 1989 fall-planted companion- and relay-intercropped kura clover. Companion-intercropped wheat harvested 17 Jul. 90, relay-intercropped wheat harvested 9 Aug. 90. Vertical bars indicate standard error of the mean.

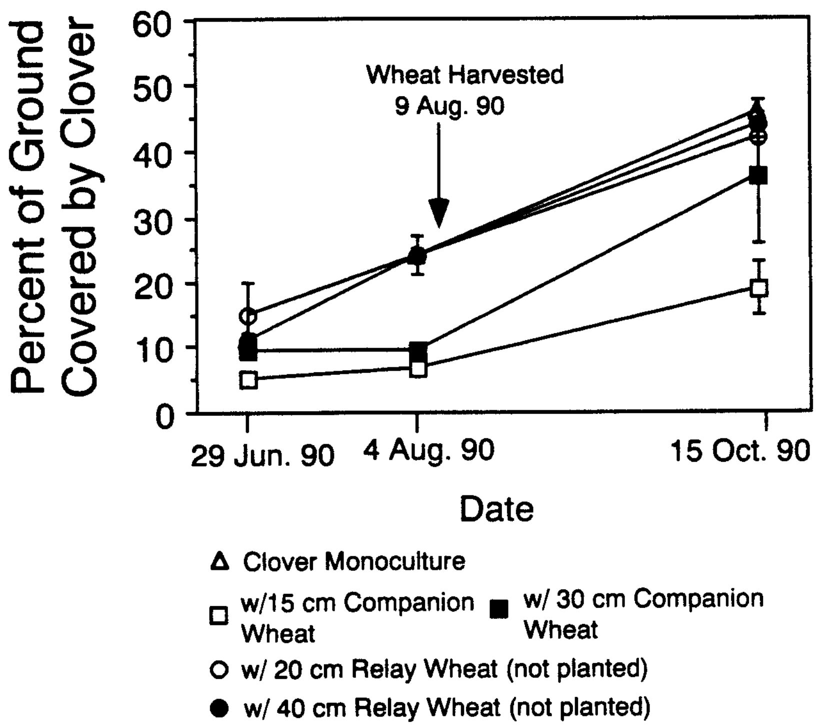

Figure 15. Percent of ground covered by 1990 spring-planted kura clover. Monoculture and relay-intercropped wheat treatments are similiar because the relay-intercropped wheat had not yet been planted. Vertical bars indicate standard error of the mean.

Table 1. 1989 spring-planted kura clover yield data from 1990 clover harvest.

Treatment †	Seed yield	Above-gound phytomass	Harvest index
	kg ha^{-1}	kg ha^{-1}	kg ha^{-1} x 10^3
Monocultured	87.4a¥	30019a	2.905
Narrow-spaced wheat companion-intercropped	28.2b	12650b	2.763
Wide-spaced wheat companion-intercropped	31.4b	11282b	2.585
Narrow- and wide-spaced wheat relay-intercropped	---	---	---
LSD (0.05) block X treat.	12.07	456.6	NS

† Kura clover relay-intercropped with wide and narrow spaced wheat could not be harvested because the previous 1990 wheat grain harvest had removed all clover seed heads.

¥ Values followed by different letters are significantly different at $P \leq 0.05$

plants produced as much seed as monocultured clover plants on a per plant basis, assuming the plants were of similar size. Wheat row spacing did not affect clover seed yield, above ground phytomass, or harvest index.

Wheat Yields: Wheat yields will determine the economic gains made by companion- or relay-intercropping. Fall-planted wheat yielded more than spring-planted wheat (Fig. 16). Narrow-spaced spring-planted wheat yielded more than wide-spaced spring wheat. Presence of clover did not affect spring wheat yields.

Fall-planted narrow-spaced wheat yields were not affected by the presence of clover. Wide-spaced, fall-planted relay-intercropped wheat yielded less than either narrow- or wide-spaced fall-planted monoculture or narrow-spaced, fall-planted relay-intercropped wheat. Kura clover in wide-spaced, fall-planted relay-intercropped wheat reduced wheat grain yields because the clover was well established and had adequate light available to maintain vigorous growth needed for effective competition with wheat.

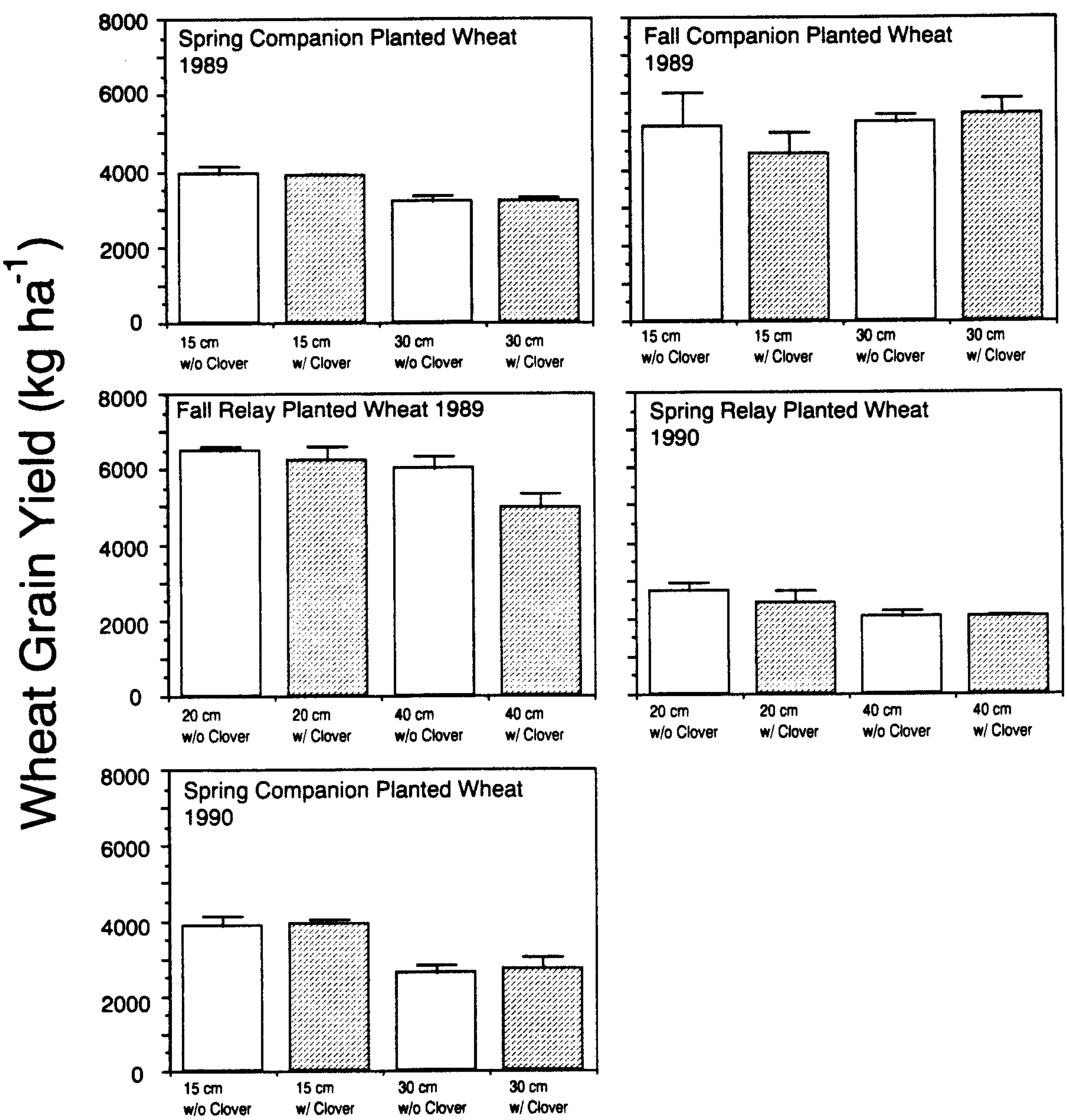

Figure 16. Wheat grain yields of companion- and relay-intercropped wheat and wheat monocultures. Vertical bars indicate standard error of the mean.

Conclusions

Companion- and relay-intercropped wheat reduced the amount of light available to kura clover plants by 50% or more. This reduction of light slowed clover growth and usually affected clover establishment adversely. Wider wheat row spacing did not consistently increase the amount of light reaching the clover canopy.

The effects of intercropping are largely determined by the timing of interspecific competition. Kura clover competed better with relay-intercropped wheat than companion-intercropped wheat because it was better established prior to the interspecific competition period. Additionally, the clover was able to recover better after relay-intercropping because the relay-intercropped wheat produced fewer competitive stress effects than companion-intercropped wheat.

Spring-planted kura clover established better than fall plantings. Fall planting kura clover is not advisable because the plants are quite small going into the winter and so are more subject to such conditions as frost heaving than spring-planted clover. Due to cold temperatures, fall-planted clover was unable to take advantage of the greater amount of light during the early period of companion-intercropping before the wheat canopy filled. Fall-planted clover with relay-intercropped wheat also did poorly because the plants were dormant during the winter and were not able to establish well prior to the time of relay-intercropping.

Because fall-planted wheat produced more grain than spring-planted wheat, and because spring-planted clover relay-intercropped with fall-planted wheat established as well as spring-planted clover monocultures, the combination of spring-planted clover followed by fall-planted wheat was the most successful of the intercropping combinations. Reasons for this success are: the clover was fairly dormant during a large part of the intercropping period and so was less susceptible to competition pressures, and the fall-wheat crop was harvested earlier during the next growing season than the spring-planted wheat companion-intercrop, allowing more time after the wheat harvest for recovery by the clover. Narrow-spaced wheat is preferred because it yielded more grain than wide-spaced wheat, and did not adversely affect clover establishment when relay-intercropped. The disadvantage of spring-planted clover with fall-planted relay-intercropped wheat is that no kura clover seed was harvested the year after establishment.

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APPENDICES

APPENDIX I.

ANOVA Tables

Table 2. Anova for percent of total PPFD reaching 1989 spring-planted kura clover canopy through wide- and narrow-spaced companion-intercropped wheat.

Source	d.f.	S.S.	M.S	F	P
Date	4	.034	.008		
Block	3	.033	.011		
Treatment	1	.077	.077	77	≤.001
Error	12	.016	.001		

Table 3. Anova for percent of total PPFD reaching 1989 spring-planted kura clover canopy through wide- and narrow-spaced relay-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Date	4	.373	.093		
Block	3	.123	.041		
Treatment	1	.145	.145	48.3	≤.001
Error	12	.041	.003		

Table 4. Anova for percent of total PPFD reaching 1989 fall-planted kura clover canopy through wide- and narrow-spaced companion-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Date	4	.042	.011		
Block	3	.003	.001		
Treatment	1	.021	.021	91.3	≤.001
Error	12	.003	.00023		

Table 5. Anova for percent of total PPFD reaching 1989 fall-planted kura clover canopy through wide- and narrow-spaced relay-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Date	3	.246	.082		
Block	3	.016	.005		
Treatment	1	.034	.034	17.0	≤.005
Error	9	.020	.002		

Table 6. Anova for percent of total PPFD reaching 1990 spring-planted kura clover canopy through wide- and narrow-spaced companion-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Date	3	.255	.085		
Block	3	.001	.00018		
Treatment	1	.039	.039	7.8	≤.025
Error	9	.043	.005		

Table 7. Anova for population density of 1989 spring-planted kura clover monocultured and planted with wide- and narrow-spaced companion-intercropped and relay-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Date	2	301.6	150.8		
Block	3	59.99	19.99		
Treatment	2	722.6	361.3	87.7	≤.001
Error	12	49.42	4.118		

Table 8. Anova for population density of 1989 fall-planted kura clover monocultured and planted with wide- and narrow-spaced companion-intercropped and relay-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Date	2	4326	2163		
Block	3	11.7	3.9		
Treatment	4	133.8	33.45	15.7	≤.001
Error	24	51.10	2.129		

Table 9. Anova for population density of 1990 spring-planted kura clover monocultured and planted with wide- and narrow-spaced companion-intercropped and relay-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Date	1	167.7	167.7		
Block	3	36.18	12.06		
Treatment	4	657.9	164.5	22.3	≤.001
Error	12	88.29	7.358		

Table 10. Anova for plant leaf number of 1989 spring-planted kura clover monocultured and planted with wide- and narrow-spaced companion-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Date	10	251.0	25.09		
Block	3	2.543	.8480		
Treatment	2	26.87	13.44	147	≤.001
Error	60	5.464	.0910		

Table 11. Anova for plant leaf number of 1989 fall-planted kura clover monocultured and planted with wide- and narrow-spaced companion-intercropped and relay-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Date	6	254.1	42.35		
Block	3	2.432	.811		
Treatment	4	176.2	44.04	188	≤.001
Error	72	16.82	.234		

Table 12. Anova for plant leaf number of 1990 spring-planted kura clover monocultured and planted with wide- and narrow-spaced companion-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Date	3	2.591	.864		
Block	3	.5630	.188		
Treatment	2	75.60	37.8	343	≤.001
Error	18	1.976	.110		

Table 13. Anova for shoot dry weight of 1989 spring-planted kura clover monocultured and planted with wide- and narrow-spaced intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Block	3	.011	.0037		
Treatment	4	.17	.0420	36	≤.001
Error	12	.014	.0012		

Table 14. Anova for root dry weight of 1989 spring-planted kura clover monocultured and planted with wide- and narrow-spaced intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Block	3	.0098	.0033		
Treatment	4	.17	.0420	50	≤.001
Error	12	.010	.00084		

Table 15. Anova for shoot dry weight of 1989 fall-planted kura clover monocultured and planted with wide- and narrow-spaced relay-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Block	3	.010	.0035		
Treatment	2	.58	.290	110	≤.001
Error	6	.016	.0027		

Table 16. Anova for root dry weight of 1989 fall-planted kura clover monocultured and planted with wide- and narrow-spaced relay-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Block	3	.053	.018		
Treatment	2	1.80	.900	29	≤.001
Error	6	.190	.031		

Table 17. Anova for shoot dry weight of 1990 spring-planted kura clover monocultured and planted with wide- and narrow-spaced intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Block	3	.0057	.0019		
Treatment	4	.12	.0310	6.7	≤.005
Error	12	.056	.0047		

Table 18. Anova for root dry weight of 1990 spring-planted kura clover monocultured and planted with wide- and narrow-spaced intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Block	3	.00095	.00032		
Treatment	4	.250	.062	7.9	≤.005
Error	12	.094	.0078		

Table 19. Anova for plant leaf area of 1989 spring-planted kura clover monocultured and planted with wide- and narrow-spaced intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Block	3	100	35		
Treatment	4	920	230	31	≤.001
Error	12	90	7.5		

Table 20. Anova for plant leaf area of 1989 fall-planted kura clover monocultured and planted with wide- and narrow-spaced relay-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Block	3	19	6.4		
Treatment	2	2600	1300	118	≤.001
Error	6	64	11		

Table 21. Anova for plant leaf area of 1990 spring-planted kura clover monocultured and planted with wide- and narrow-spaced intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Block	3	35	12		
Treatment	4	1000	260	6.5	≤.001
Error	12	480	40		

Table 22. Anova for percent ground covered by 1989 spring-planted kura clover monocultured and planted with wide- and narrow-spaced companion-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Date	4	11879	2969		
Block	3	3415	1138		
Treatment	2	36292	18146	333	≤.001
Error	24	1306	54.45		

Table 23. Anova for percent ground covered by 1989 fall-planted kura clover monocultured and planted with wide- and narrow-spaced companion-intercropped and relay-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Date	3	324	108		
Block	3	183	61.2		
Treatment	4	2489	622	121	≤.001
Error	36	185	5.16		

Table 24. Anova for percent ground covered by 1990 spring-planted kura clover monocultured and planted with wide- and narrow-spaced companion-intercropped and relay-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Date	2	7696	3848		
Block	3	109	36.5		
Treatment	4	2615	653	18	≤.001
Error	24	863	35.9		

Table 25. Anova for seed yield of 1989 spring-planted kura clover monocultured and planted with wide- and narrow-spaced companion-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Block	3	2010	670		
Treatment	2	8312	4156	85.3	≤.001
Error	6	292	48.7		

Table 26. Anova for above-ground phytomass of 1989 spring-planted kura clover monocultured and planted with wide- and narrow-spaced companion-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Block	3	5107882	1702627		
Treatment	2	273927432	136963716	1966	≤.001
Error	6	2.03×10^{-10}	69648		

Table 27. Anova for harvest index of 1989 spring-planted kura clover monocultured and planted with wide- and narrow-spaced companion-intercropped wheat.

Source	d.f.	S.S.	M.S.	F	P
Block	3	.017	.0055		
Treatment	2	.022	.0011	.478	>.50
Error	6	.014	.0023		

Table 28. Anova for wheat grain yield of 1989 spring-planted wide- and narrow-spaced companion-intercropped and monocultured wheat.

Source	d.f.	S.S.	M.S.	F	P
Block	3	493267	164422		
Treatment	3	2002389	667463	15.7	≤.001
Error	9	383421	42602		

Table 29. Anova for wheat grain yield of 1989 fall-planted wide- and narrow-spaced relay-intercropped and monocultured wheat.

Source	d.f.	S.S.	M.S.	F	P
Block	3	1965133	655044		
Treatment	3	5197960	1732653	7.19	≤.01
Error	9	2167353	240817		

Table 30. Anova for wheat grain yield of 1989 fall-planted wide- and narrow-spaced companion-intercropped and monocultured wheat.

Source	d.f.	S.S.	M.S.	F	P
Block	3	5958588	1986196		
Treatment	3	2326669	775556	.73	>.50
Error	9	9587336	1065259		

Table 31. Anova for wheat grain yield of 1990 spring-planted wide- and narrow-spaced relay-intercropped and monocultured wheat.

Source	d.f.	S.S.	M.S.	F	P
Block	3	1288537	429512		
Treatment	3	1368618	456206	3.97	≤.05
Error	9	1033525	114836		

Table 32. Anova for wheat grain yield of 1990 spring-planted wide- and narrow-spaced companion-intercropped and monocultured wheat.

Source	d.f.	S.S.	M.S.	F	P
Block	3	892362	297454		
Treatment	3	5823917	1941305	10.58	≤.005
Error	9	1650855	183428		

APPENDIX II.

Supplementary Table

Table 33. Dates and amounts of sprinkle irrigation water applied to kura clover.

Planting Time	Date	Amount of Water
		--- mm ---
Spring 1989	29 Apr. 89	16
	9 May 89	16
	6 Jun. 89	16
	24 Jun. 89	16
	25 Jun. 89	19
	30 Jul. 89	24
	19 Jul. 90	24
	24 Jul. 90	24
	20 Aug. 90	24
Fall 1989	19 May 90	16
	18 Jul. 90	24
	23 Jul. 90	24
	22 Aug. 90	24
Spring 1990	5 May 90	16
	17 Jul. 90	24
	25 Jul. 90	24
	24 Aug. 90	24