

The Growth and Competitiveness of Round-leaved Mallow (*Malva pusilla* Sm.)
in Spring Wheat (*Triticum aestivum* L.)

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of

Graduate Studies

The University of Manitoba

by

Kenneth Peter Nickel

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science

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THE GROWTH AND COMPETITIVENESS OF ROUND-LEAVED MALLOW
(Malva pusilla Sm.) IN SPRING WHEAT (Triticum aestivum L.)

BY

KENNETH PETER NICKEL

A thesis submitted to the Faculty of Graduate Studies of
the University of Manitoba in partial fulfillment of the requirements
of the degree of

MASTER OF SCIENCE

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ABSTRACT

Nickel, K.P., M.Sc., The University of Manitoba, 1989. The growth and competitiveness of round-leaved mallow (*Malva pusilla* Sm.) in spring wheat (*Triticum aestivum* L.). Major Professor: Dr. I.N. Morrison, Department of Plant Science.

Field experiments were conducted in 1987 and 1988 to determine and explain the effects of round-leaved mallow (*Malva pusilla* Sm.) interference on the yield of spring wheat (*Triticum aestivum* L.). The results were analyzed using linear regression procedures, where spring wheat yield was regressed against mallow plant density. A significant spring wheat yield loss occurred in only one of seven trials conducted over the two years. In this trial, where wheat densities ranged from 195 to 310 plants m⁻², mallow densities of 225 plants m⁻² reduced wheat seed yields by 13% as described by the regression equation $y = 346.1 - 0.2x$.

The growth of round-leaved mallow plants grown alone or within a spring wheat crop was examined using periodic plant sampling and analysis. The results were fitted to a logistic function used as a biological model of plant growth. Interference from spring wheat impeded the growth of round-leaved mallow plants by approximately 98%. The growth of round-leaved mallow plants with wheat was virtually arrested by mid-season due to shading and other interference effects. At the densities tested, round-leaved mallow plants had minimal effect on spring wheat yield due to this extreme suppression of mallow growth.

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INTRODUCTION

Round-leaved mallow (*Malva pusilla* Sm.) is native to Eurasia but has become an established weed in most Canadian provinces (Makowski and Morrison 1989). The names and identification of round-leaved mallow and two other closely related weed species, common mallow (*Malva neglecta* Wallr.) and small-flowered mallow (*Malva parviflora* L.), have often been confused in North America. Through field surveys Makowski (1987) determined that round-leaved mallow (*Malva pusilla*) was the only species present in Manitoba and Saskatchewan fields.

In Manitoba, round-leaved mallow has historically been an annual weed of gardens and waste places (Frankton and Mulligan 1987). However, in recent years it has been encroaching into cultivated fields, especially in the central region of the province (Thomas and Wise 1988). Round-leaved mallow can cause significant yield losses in both competitive (spring wheat) and relatively non-competitive (flax and lentils) crops (Budzinsky 1987; Makowski 1987). Also, round-leaved mallow plants may impede harvesting operations and cause serious contamination losses through reduced crop quality and increased problems with crop storage (Makowski and Morrison 1989).

Round-leaved mallow is not readily controlled by any currently registered selective herbicide. While several products are effective on round-leaved mallow seedlings, they do not provide a consistently high level of control in field situations. A mycoherbicide is being developed from a naturally occurring pathogen, *Colletotrichum gloeosporioides* (Penz.) Sacc. f. sp. malvae (C.g.m.),

and has potential for future use as a bio-control agent specific for round-leaved mallow (Mortensen 1988).

In light of the increasing occurrence of round-leaved mallow in cultivated fields, the potential for large crop yield losses, and the lack of available control measures, this research project was initiated. The purpose of this project was to quantify and explain round-leaved mallow interference in spring wheat under Manitoba conditions. This was accomplished through competition trials and the use of plant growth analysis techniques.

This thesis was written in manuscript style following the format of Weed Science.

CHAPTER 1

REVIEW OF LITERATURE

1.1 ROUND-LEAVED MALLOW

Nomenclature

Malva pusilla Sm. (= *Malva rotundifolia* L.) (round-leaved mallow) is closely related to *Malva neglecta* Wallr. (common mallow), and *Malva parviflora* L. (small-flowered mallow), two other weed species present in Canada (Makowski and Morrison 1989). The name '*Malva rotundifolia* L.' has been used in North America to describe all three of these species. In addition to providing a detailed description of *M. pusilla*, Makowski and Morrison (1989) chronicle the taxonomic confusion involving similar species in the genus. *M. pusilla* will be referred to as mallow throughout the remainder of this thesis.

Biology

The growth habit and biology of mallow has recently been reviewed by Makowski and Morrison (1989). Briefly, mallow is normally a prostrate plant with branches radiating from a short central stem attached to a long taproot. Each branch exhibits indeterminate growth and can exceed 1 meter in length. The leaves are alternate, reniform in shape, 2.5 - 7.5 cm in diameter, and have petioles from 2 to 24 cm long (Makowski and Morrison 1989).

The flowers of mallow occur in groups of up to 20 per leaf axil as early as 4 weeks after plant emergence (Carlson and Eberlein 1983; Makowski and Morrison 1989). Flowers are initiated throughout the growing season as the

branches elongate (Budzinsky 1987). Each flower results in a multicarpellate fruit containing 10 to 12 one-seeded mericarps (Makowski and Morrison 1989). Mature mallow seed is present in these mericarps 16 to 18 days after flowering (Abdullaeva 1966). Mature seed is produced from 7 weeks after plant emergence through to the end of the growing season. The mallow seed has a hard seed coat which usually prevents imbibition until broken through natural aging or other stresses (Makowski and Morrison 1989).

Weedy Nature

Mallow is native to Eurasia and was introduced to North America by early European settlers. Herbarium specimens examined by Makowski (1987) indicated that mallow (*M. pusilla*) was present in Canada by 1878 and in Manitoba (Morden) by 1896.

In recent years mallow has been spreading from traditional sites such as farmyards, gardens, and waste places, into field edges (Looman and Best 1979; Makowski and Morrison 1989). Conventional tillage practices have contributed to the spread of this weed further into infested fields. Subsequent contamination of crop harvests used for seed has lead to introduction of mallow to additional fields. Evidence supporting the latter means of spread was reported in the 1981 Manitoba Seed Grain Survey (Anonymous 1982). Nearly 1% of the grain drills sampled contained crop seed contaminated with mallow seed.

The increase of mallow populations on crop land has been observed and measured in the prairie provinces and reported in provincial weed surveys (Thomas and Wise 1983; 1987). In Manitoba, mallow has increased in ranking

from being 33rd in relative abundance on crop land in 1978, to 24th in 1986 (Thomas and Wise 1978; Thomas and Wise 1988). Mallow densities of up to 43 plants m⁻² were recorded in the 1986 Manitoba weed survey (Thomas and Wise 1988). These results probably understate the extent of mallow infestations on cultivated fields because the sampling technique deliberately avoids field headlands where mallow is observed to occur most commonly (Sturko 1987).

Mallow has the potential to be a persistent weed in cultivated fields. *M. rotundifolia* (possibly *M. pusilla*) was reported by Carlson and Eberlein (1983) to produce more than 5,000 seeds per plant when grown in a pure stand. In addition, in Beal's viability test *M. rotundifolia* seed remained viable in the soil for up to 100 years (Kivilaan and Bandurski 1981). The combination of a hard seed coat, long term seed viability, and prolific seed production ensure the continued presence of this species once introduced into a field.

Carlson and Eberlein (1983) observed that *M. rotundifolia* seed germination in the field occurred throughout the growing season. This corresponded with the findings of Makowski (1987) who noted that, while mallow seed could germinate at temperatures as low as 5C, optimum germination temperatures were in the range of 15 to 30C.

1.2 COMPETITION

Definition

Plant competition was described by Clements et al. (1929) as being a purely physical process which "...arises from the reaction of one plant upon the physical factors about it and the effect of the modified factors on its competitors". They go on to identify water, nutrient material, light, and heat as the factors that are modified. Competition begins when the immediate supply of a single required factor falls below the combined demand of the plants. The term "interference" has been used recently to include allelopathic and other factors not normally associated with the traditional concept of plant competition (Harper 1977).

Competition Study Designs

Plant competition between crops and weeds is of major concern due to the potential magnitude of economic losses. Many experiments have been conducted to measure crop yield losses due to increasing population densities (Dew 1972; Gillespie and Miller 1984; Beckett et al. 1988) and proximity (Higgins et al. 1984) of a weed species. Generally these competition experiments have been conducted using either an additive or a replacement series design.

Additive designs are relatively simple and have often been used in competition studies involving a single weed species in a crop (Oliver et al. 1976; Gillespie and Miller 1984; De St. Remy et al. 1985). The indicator (crop) species is held at a constant density while the second (weed) species is included at various densities (Jolliffe et al. 1984). The aim of this design is to determine the

density of the weed species required to cause a "significant" loss in yield (Dew 1972).

Replacement series designs have been widely used in competition experiments since 1960 (Jolliffe et al. 1984). This design involves establishing a constant total density of plants with the proportion of each of two species varied inversely to the other. Pure stands of each species plus a range of mixtures of the two are used. The performance of each species in a mixture relative to a pure stand is used to determine competitiveness.

There are problems associated with the interpretation of results using either additive or replacement series designs (Harper 1977; Jolliffe et al. 1984, Firbank and Watkinson 1985; Connolly 1988). The main problem with the additive design is that the proportional composition and the density of the mixture are both altered which confounds their effects (Harper 1977; Rejmanek et al. 1989). While the replacement series design eliminated this problem (Harper 1977), the constant density of the mixture constitutes a major weakness as the effects of interspecific and intraspecific competition cannot be separated (Jolliffe et al. 1984; Firbank and Watkinson 1985).

To differentiate between interspecific and intraspecific competition, Jolliffe et al. (1984) proposed a model requiring the addition of yield measurements of monoculture stands of each plant species, over a range of densities, to the traditional replacement series design. The results of monoculture experiments were used to develop a projected yield line excluding the effects of both intraspecific and interspecific competition. This line then served as a reference

for determining intraspecific and interspecific competition effects from monoculture and two-species mixture results.

Firbank and Watkinson (1985) stated that the ideal analysis of competition "should generate a model of competition that allows the yields of both species in a binary mixture to be estimated at any combination of frequency and density". The model proposed by Jolliffe *et al.* (1984) describes the effects of proportion on both interspecific and intraspecific competition in a two-species mixture. However, this model does not directly address the effects of total density, although Jolliffe *et al.* (1984) do suggest including many experiments with different total densities of the two-species mixtures.

Firbank and Watkinson (1985) presented a plant competition model which incorporated monoculture and mixed species yield data from a wide range of total plant densities. Their model provided both yield and plant mortality estimates for either species at any given proportion and density.

Connolly (1988) held that additive and replacement series designs were inappropriate for competition studies as they are, among other things, frequently biased in favor of the larger species and may therefore be misleading. He supported the use of the type of multivariate response model presented by Firbank and Watkinson (1985) which related individual plant yield to the densities of both weeds and crop species.

Reciprocal yield models have also been proposed as a means of overcoming the weaknesses of additive and replacement series designs

(Connolly 1988; Roush et al. 1989; Rejmanek et al. 1989). Reciprocal yield models are based upon the linear relationship between the reciprocal of mean yield per plant and plant density, for a single plant species. As interspecific and intraspecific competition effects are considered to be additive, this model can be extended to include species mixtures using multiple regression (Roush et al. 1989). The reciprocal yield model incorporates the effects of both density and proportion, and describes the contribution of intraspecific and interspecific competition through simple coefficients (Roush et al. 1989; Rejmanek et al. 1989).

In contrast to new competition designs providing extensive analysis of interference between species, Hume (1985) proposed modifications to the commonly used additive design to increase the accuracy of yield loss estimates. Hume (1985) argued that weed-crop competition studies of additive design may yield inaccurate crop loss estimates if crop densities are not accounted for. He demonstrated that in certain field situations, differences in crop (spring wheat) density accounted for more of the variability in crop yields than did the density of weeds present. A paired quadrat design is presented by Hume (1985) in which both a weed-free and a weedy quadrat of known crop densities are compared. Multiple regression is recommended as a means of describing the relationship between crop yield loss and weed density with the differences in crop density held constant. The proposed changes in design and analysis compensated for the effects of variation in crop density which were not considered in the additive design.

Plant Competition Models

Competition studies of additive series design have generally shown that as densities of the second species (or weed) increase; the yield of the indicator species (or crop) decreases (Jolliffe et al. 1984; Zimdahl 1980). The crop yield loss per additional weed is not constant over the range of weed densities however. Zimdahl (1980) presented the commonly held, but unsupported, view that the relationship between crop yield and weed density is sigmoidal in nature. In this approach the first few weeds added to a crop were assumed not to cause crop yield loss.

Cousens et al. (1984) reviewed the sigmoidal and other models of the weed density - yield loss relationship. They concluded that while yield losses at low weed densities may not be demonstrable due to inherent variability, competition experiment results did not support the sigmoid model. Instead, a hyperbolic model is presented in which the relationship between low weed densities and crop yield loss is close to linear. They propose that the addition of each weed at these low densities will have an additive effect on crop yield. Intraspecific competition between weeds is assumed to be absent due to the large mean distance separating them. Cousens et al. (1984) reasoned that as the density of weeds is increased there will be a corresponding decrease in the mean distance between them leading to increased intraspecific competition. The hyperbolic yield response model accommodates the decreasing individual competitive effect of each weed as their density increases.

Cousens (1985a) compared the rectangular hyperbola and 17 other models applied to 22 data sets from previously reported competition studies. The rectangular hyperbola provided the best description of these data sets.

Two recent studies of "volunteer" barley (*Hordeum vulgare* L.) interference in a canola (*Brassica napus* L.) crop support the arguments of Cousens et al. (1984) in favoring the rectangular hyperbolic model. O'Donovan et al. (1988) used the rectangular hyperbolic model to describe the relationship between canola yield loss and average "volunteer" barley densities of up to 231 plants m⁻². The model provided a reasonable description of the pooled data as indicated by the R² value of 0.63. For comparison purposes, the same data was also fitted to a multiple regression model. The R² value for this model was also 0.63, indicating that both models fitted the data equally well. However, the hyperbolic model provided a more biologically meaningful estimation of yield loss. The multiple regression model predicted a 4% canola yield loss when volunteer barley was not present, and an infinite yield loss at high volunteer barley densities (O'Donovan et al. 1988).

Marshall et al. (1989) used various regression procedures, to analyze the data from another study involving "volunteer" barley in canola. In this study, simple linear regression was the model which best described the relationship between these two species. The "volunteer" barley densities in these experiments ranged up to approximately 50 plants m⁻². These low densities would encompass only the linear portion of the hyperbolic canola yield response curve reported by O'Donovan et al. (1988).

Friesen *et al.* (1989) used rectangular hyperbolic models to describe flax (*Linum usitatissimum* L.) yield response to increasing densities of "volunteer" wheat (*Triticum aestivum* L.) and barley. The rectangular hyperbolic model fitted the data well as the range of volunteer species densities was wide enough to include the departure of yield loss data from its linear response to weed density.

Many competition studies have been analyzed using low order polynomials to describe data and to estimate crop yield losses due to weeds (Beckett *et al.* 1988; McGregor *et al.* 1988; Legere and Schreiber 1989; Marshall *et al.* 1989; Wall and Friesen 1989). However, the results of polynomial models are often biologically meaningless (Cousens 1985b). Quadratic models have yielded estimates of crop yield losses exceeding 100% (Wall and Friesen 1989) as well as predictions of crop yield decreases and then rises as weed density increases (Beckett *et al.* 1988). An additional problem with using these models is determining the level of polynomial to be used. In the past, linear models have often been fitted to data which appeared to be curvilinear in nature (McGregor *et al.* 1988; Smith 1988).

Competition Studies Involving Round-leaved Mallow

Several competition studies have been undertaken to determine the effect of mallow on the yields of field crops. Carlson and Eberlein (1983) determined that *M. rotundifolia* (possibly *M. pusilla*) at densities of 33 plants m⁻² did not cause reductions in the yield of wheat, even when both species were seeded on the same date. Budzinsky (1987) observed a 20% reduction in spring wheat yields associated with mallow (*M. pusilla*) densities of up to 87 plants m⁻² in trials

done in Manitoba in 1985. She also reported a 97% yield reduction in flax due to the presence of mallow at densities averaging 39 plants m^{-2} .

The most thorough study of competition involving mallow was done by Makowski (1987) in Saskatchewan. The paired quadrat method recommended by Hume (1985) was used in a series of trials in spring wheat and lentils. Average densities of 139 and 338 plants m^{-2} reduced wheat yields 30 and 85%, respectively. Lentil yields were decreased 60 and 85% in response to average mallow densities of 115 and 150 plants m^{-2} , respectively.

Whereas competition studies involving other weed species have shown good correlations between weed density and crop yield losses (Gillespie and Miller 1984; De St. Remy *et al.* 1985), Makowski (1987) determined that this was not the case with mallow. There was a strong correlation in her data between the late season mallow biomass (total above ground shoot dry weight) and crop yield decreases, but not between early season weed density and crop yield. The hyperbolic crop yield loss model fitted her data more closely when mallow biomass was used in place of plant density. Makowski determined crop yield reductions of 50% were associated with 120 g m^{-2} and 200 g m^{-2} mallow biomass at harvest for wheat and lentils, respectively. Neither crop produced any harvestable seed when the mallow biomass at harvest was 800 g m^{-2} .

Makowski (1987) noted that the mallow densities required to reach similar biomass levels at harvest were much higher in the more competitive wheat crop than in the lentils. There was no other correlation between the plant density and biomass at harvest of mallow. Makowski concluded that because weed density

is irrelevant and harvest biomass is measured after the competitive effects have occurred, both measurements are useless for prediction of crop losses due to mallow. She suggested that the stage of development of mallow relative to the crop early in the season be used in developing crop loss predictions.

Makowski (1987) observed that mallow morphology is greatly affected by competition from wheat. Mallow growing with wheat was more erect and had fewer leaves, branches, and fruits than mallow growing alone or in a less competitive crop such as lentils. Carson and Eberlein (1983) obtained similar results with *M. rotundifolia* grown in competition with wheat. They also measured the regrowth of *M. rotundifolia* after the wheat crop was removed and found no additional seed was produced.

1.3 MATHEMATICAL GROWTH ANALYSIS

Introduction

Pavlychenko and Harrington (1934) were among the first researchers to measure the effects of interspecific competition on plant growth. The analysis of plant growth has ranged from the detailed approach of Pavlychenko and Harrington (1934), to the simple measurement of plant biomass used by Makowski (1987). In recent years, mathematical growth analysis techniques have occasionally been included in competition studies to provide additional information on the competitive interaction between species (Oliver et al. 1976; Hagood et al. 1980; Flint and Patterson 1983; Fernandez and Miller 1987).

Conventional (or mathematical) plant growth analysis involves the transformation of simple observations of size into indices of both the presence and assimilatory performance of plant components (Jolliffe and Courtney 1984). The remainder of this review will be limited to the discussion of the general approaches to mathematical growth analysis and its use in competition studies. A thorough discussion of the growth indices, including definitions and methods of derivation, can be found in Kvet et al. (1971), Causton and Venus (1981), and Hunt (1982).

Approaches

There are two recognized and distinct approaches which may be used for mathematical growth analysis. Both approaches require a series of harvests over time involving the destructive sampling of plants. The original "classical" approach requires infrequent but large harvests involving many plants. All growth indices are determined for the interval between two successive harvest dates (Hunt 1982). The alternative "functional" approach involves smaller but more frequent harvests. Using this approach, the data is fitted to curves with instantaneous values of the growth indices derived from the equation of the predicted curve (Hunt 1982).

The greatest advantage of the functional approach is its smoothing effect on irregular fluctuations in the harvest data to more closely approximate reality (Hunt 1982). All data are included in the calculation of the fitted curve, reducing the effect of any unusual results. If irregular results represent genuine events, however, the smoothing of data will lead to a net loss of information (Buttery 1969). With the classical approach, inaccurate data from one harvest results in

the growth indices calculated for the harvest intervals prior to and after this harvest date being distorted (Williams 1946). While the functional approach is currently preferred for most situations, the classical approach is useful when growth rates between specific harvest dates are of primary concern (Hunt 1982).

Curve Fitting

The major difficulty with the functional approach is the selection of an equation which best describes the harvest data (Buttery 1969). This equation must reflect a balance between statistical and biological considerations (Hunt 1982). While the equation must fit the primary data, it must not match it so closely that a smoothing effect is not achieved. The equation should also reflect the biological patterns expected by the researcher (Hurd 1977).

The main group of equations used in the functional approach are polynomial exponential functions (Causton and Venus 1981). These equations share many relatively simple mathematical and statistical properties and may be easily fitted to data by regression procedures. The choice of polynomial in the literature has often been restricted to the second order (quadratic) to avoid over-fitting the data (Vernon and Allison 1963; Buttery 1969; Nicholls and Calder 1973). Nicholls and Calder (1973) have proposed a statistical test to determine the appropriate order polynomial for a given data set. Beginning with a linear model, higher order polynomials are tested until the highest is found where the sum of squares due to 'lack of fit' is still significant when compared to the within sample sum of squares.

Polynomial equations are used to accurately describe the data. The function parameters are not ascribed biological significance, but rather, all comparative information is achieved using the derivatives of these parameters (Hunt 1982).

Asymptotic non-linear equations, often described as biological models, have been used in the functional approach to plant growth analysis (Venus and Causton 1979). Due to their sigmoidal shape and asymptotic nature, biological models are well suited to the modeling of determinate growth systems such as individual plant organs (Dennett *et al.* 1978; Thomas and Potter 1985). Asymptotic functions are susceptible to errors in modeling entire plant growth if the data do not approach an asymptote or if they display a decline at the end of the measurement period (Hunt 1982). However, this has not prevented their use in entire plant analysis (Causton and Venus 1981).

In addition to a simple curve-fitting role, asymptotic non-linear equations involve at least three estimated parameters which have been assigned biological significance. The three common parameters indicate values for the lower asymptote or starting size, upper asymptote or carrying capacity for that environment, and rate constant or intrinsic rate of increase (Hunt 1982).

The non-linear equation used most frequently is the four parameter Richards function (Richards 1959; Causton and Venus 1981). The fourth parameter allows for a variable point of inflection resulting in a curve less rigid in shape than one derived using a three parameter function (Hunt 1982).

The logistic (or autocatalytic) function is a special case of the Richards function in which the resulting curve is symmetric about a central inflection point (Hunt 1982) (Chapter 3, Figure 7). As it has only three estimated parameters it is easier to calculate than the Richards function but this is achieved through loss of flexibility.

The logistic function was employed in some of the earliest attempts at plant growth analysis using curve-fitting techniques (Gregory 1921). Use of this function was based on the assumption that the growth rate of plants was controlled by a single "master" autocatalytic chemical reaction and therefore diminished when this theory was disproved (Causton and Venus 1981).

The logistic function has been used to describe plant growth for comparison purposes. The inflection point represents the point of maximum absolute growth rate (AGR_{max}) of the plant. The actual rate at this point is determined by the slope of the predicted curve. The upper asymptote represents the maximum plant size as time goes to infinity, or, the carrying capacity of the environment.

The logistic function has been used as a biological model to describe subterranean clover (*Trifolium subterraneum* L.) shoot dry weight accumulation per hectare over time, in studies of the effects of seeding dates, densities (Silsbury and Fukai 1977), and temperature (Fukai and Silsbury 1976). Silsbury and Fukai (1977) were especially pleased with the degree to which the logistic function fitted all data sets.

Silisbury *et al.* (1979) used the logistic function to describe the effects of sowing density on patterns of Medic (*Medicago truncatula*) dry matter increase per hectare. The logistic function described the data well in spite of the wide range of sowing densities (1 to 1,000 kg ha⁻¹). However, the logistic function was weak at the end of the study period as it could not accommodate the dry matter decrease associated with plant senescence.

The logistic function was also used in studies of pasture regrowth (Hunt 1970), germination and seedling growth (Hsu *et al.* 1984), and tobacco callus growth (Hunt and Loomis 1976).

Growth Analysis in Competition Studies

Milthorpe (1961) stated that interspecific plant competition could "best be understood by analyzing the time-courses of growth of the components during each growing season". The growth characteristics of a plant, which determine its ultimate size and production of reproductive structures, are affected by changes in the local environment caused by competition. Milthorpe (1961) proposed the use of "classical growth analysis" to measure the relative performance of each individual in a community using an index of growth over time. He reviewed the results of many previous competition studies in his analysis of the nature of interspecific competition. Milthorpe concluded that competitive advantage among plants depended on initial size at emergence, the time of emergence relative to other species, and on relative growth-rate (RGR). The major effect of competition was reported to be a decreased rate of growth and delayed development and maturity of the subordinate species.

A number of recent competition experiments have included measurement of plant growth using mathematical plant growth analysis techniques. One of the reasons for their inclusion has been to determine the required growth factor being affected by a competitor species. Welbank (1961) studied the growth of an indicator plant species (*Impatiens parviflora*) to determine the effect of competition from an associated weed species (*Agropyron repens*) on the availability of nitrogen and water. He compared the growth parameters of indicator plants growing alone and with *A. repens*, either with or without additions of these factors. Competition for a factor was determined by the degree to which the addition of each factor compensated for the competitive effect of *A. repens*. The plant net assimilation rate (NAR) and relative growth-rate (RGR) measurements of indicator plants indicated that competition from *A. repens* involved both factors, and that water was probably more important.

Oliver et al. (1976) included growth analysis of both tall morningglory (*Ipomoea purpurea*) and soybean (*Glycine max*) in a study of competition between the two species. As tall morningglory densities increased, there was a corresponding reduction in the crop growth-rate (CGR) and leaf area index (LAI) of weedy soybean relative to weed-free soybean. These derived growth parameters were used to determine the onset and extent of competition effects on soybean plants. Oliver et al. (1976) were able to determine which tall morningglory growth characteristics contributed most to its competitiveness. Increased tall morningglory LAI and total size, which were achieved earlier at higher weed densities, were closely associated to decreases in soybean growth and yield. Similar results were reported from trials conducted by Hagood et al. (1980; 1981) who investigated the effects of velvetleaf (*Abutilon theophrasti*) and

jimsonweed (*Datura stramonium*) competition on the growth and yield of soybeans. In addition they determined that as weed densities increased, the added intraspecific competition resulted in individual weed plants being much smaller than those growing at lower densities. The average plant dry weights decreased approximately 50% when velvetleaf densities increased from 5 to 20 plants m^{-2} and when jimsonweed densities increased from 4 to 16 plants m^{-2} .

Higgins et al. (1984) used plant growth analysis to measure the effect of relative weed (velvetleaf) location on the growth of crop (soybean) plants. Analysis of crop plants growing in weed-proximate or weed-distant (75 cm from the nearest weed) locations indicated that only crop plants near the weed were affected, displaying lower CGR, RGR, and dry weight accumulation.

The effects of elevated carbon dioxide levels on competition between plants was also examined using plant growth analysis. The growth of C₃ and C₄ weed and crop plants grown at three different carbon dioxide concentrations was measured by Patterson and Flint (1980). The crop/weed relationships at high atmospheric carbon dioxide levels were projected from the results to favor C₃ plants. Patterson et al. (1984) tested this hypothesis by directly evaluating carbon dioxide enrichment effects on competition between C₄ johnsongrass (*Sorghum halepense*) and C₃ soybean plants. Growth analysis of the two species indicated that at higher carbon dioxide levels, the dry matter production of soybean increased significantly relative to johnsongrass, largely due to an increase in leaf area duration (LAD).

There are several examples of the use of plant growth analysis to measure the effects of temperature on the competitive relationships between plants. Flint and Patterson (1983) studied interference and temperature effects on the growth of soybean, common cocklebur (*Xanthium pensylvanicum*), and smooth pigweed (*Amaranthus hybridus*). Smooth pigweed, a C₄ plant, was not as competitive as the other two species at low temperatures, but it increased as a competitor at elevated temperatures through a relatively large increase in its LAD. Flint et al. (1983) conducted a related experiment using cotton (*Gossypium hirsutum*), spurred anoda (*Anoda cristata*) and velvetleaf. They determined that the competitiveness of cotton relative to the two weeds was higher at elevated temperatures. This temperature effect was attributed to relatively larger increases in LAD and smaller decreases in NAR in the cotton compared to in the other two species at the higher temperature level. Plant growth analysis techniques facilitated the measurement of plant growth responses in these two experiments even though the final harvests were only 34 and 39 days after planting, respectively.

Another experiment exploring effects of temperature and weed density on plant competition was conducted by Wulff (1987) using *Amaranthus dubius* (L.) in soybean and sorghum (*Sorghum bicolor*) crops. Higher temperatures were associated with increased weed biomass at most densities in either crop.

Patterson et al. (1986) included temperature treatments in their test of the competitiveness of two closely related weeds, Texas panicum (*Panicum texanum*) and wild proso millet (*Panicum miliaceum*). They determined that at higher temperatures Texas panicum was the dominant weed, while in cooler

temperatures wild proso millet was competitively superior. They used these results to predict in which climatic regions the two weeds would likely occur and be most competitive.

Mathematical plant growth analysis parameters derived from plants growing alone or in pure stands have been used to predict the performance of plant species in competitive situations (Grime and Hunt 1975; Patterson 1979). Such efforts have met with mixed success. In one such experiment, Roush and Radosevich (1985) conducted a competition study involving four annual weed species combined with a detailed analysis of each species grown alone. From the competition results the weeds could be arranged in a hierarchy of aggressiveness relative to one another. The same hierarchy could also be found using the dry weight, NAR, and leaf area ratio (LAR) (in reverse order) values derived from the growth analysis of isolated plants. They concluded these parameters, derived from plants grown in isolation, may be of use in predicting the competitiveness of a weed species.

In contrast, the results of Williams (1963) illustrate potential problems in using growth analysis parameters for predicting competitiveness. Williams tested subterranean clover (*Trifolium subterraneum* L.), rose clover (*T. hirtum* All.), and crimson clover (*T. incarnatum* L.) grown in pure stands and in mixtures. He found all three species to have similar net assimilation rate (NAR) and RGR values when grown in pure stands. In mixtures, however, the subterranean clover had RGR and NAR parameter estimates 40 and 67% higher than crimson clover, respectively, and more than 3 times that of rose clover.

CHAPTER 2

ROUND-LEAVED MALLOW INTERFERENCE IN SPRING WHEAT

Abstract. Field experiments were conducted in 1987 and 1988 in Manitoba to determine the effects of mallow (*Malva pusilla* Sm.) interference on the yield of spring wheat (*Triticum aestivum* L. 'Katepwa'). The results were analyzed using linear regression procedures, where spring wheat yield was regressed against mallow plant density. A significant spring wheat yield loss occurred in only one of seven trials conducted over the two years. In this trial, mallow densities of 225 plants m⁻² reduced seed yields of wheat by 13% as described by the regression equation $y = 346.1 - 0.2x$. This corresponded with a 14% reduction in wheat head numbers. Variation in wheat density did not significantly influence weed-free crop yields or estimates of crop yield losses due to mallow interference. The results indicate that mallow interference is unlikely to cause wheat yield reductions at the mallow densities commonly occurring in Manitoba wheat fields.

INTRODUCTION

Mallow (*Malva pusilla* Sm.) is a common weed of yards, gardens, and waste areas in western Canada (Frankton and Mulligan 1987), and recently has been encroaching onto cultivated fields. In Manitoba, mallow was ranked the 24th most abundant weed of field crops in the 1986 Weed Survey (Thomas and Wise 1988), up from 33rd in 1978 (Thomas 1978). Mallow occurred in 5.6% of Manitoba fields surveyed in 1986 at population densities of up to 43 plants m⁻².

Once introduced, mallow persists in a field because the seed can remain viable in the soil for several decades (Kivilaan and Bandurski 1981). The lack of

selective herbicides that effectively control the weed also has contributed to the increased occurrence of mallow.

Mallow can cause substantial yield losses in crops that are not highly competitive. In Manitoba, mallow densities of up to 39 plants m^{-2} decreased the yield of flax by more than 90% (Budzinsky 1987). In Saskatchewan, densities of 115 and 150 plants m^{-2} reduced the yield of lentils by 60 and 85%, respectively (Makowski 1987).

Highly competitive crops are less affected by mallow interference. Spring wheat yields in Manitoba were reduced by only 20% at mallow densities ranging from 56 to 87 plants m^{-2} (Budzinsky 1987). In Saskatchewan, densities of 139 and 338 mallow plants m^{-2} decreased spring wheat yields by 32 and 70%, respectively (Makowski 1987). Neither Budzinsky (1987) nor Makowski (1987) used accepted regression procedures to relate crop yield losses to mallow density. Instead, means accompanied by standard errors were reported.

Makowski (1987) determined that crop yield losses were poorly correlated with mallow density, but that a significant correlation existed between crop yield losses and mallow shoot dry weight at crop harvest.

For yield loss models to be useful for farm management decisions, it is necessary that they be based upon a parameter measured early in the growing season. The objective of this research was to determine the effects of various densities of mallow, occurring shortly after crop establishment, on the growth and yield of spring wheat.

MATERIALS AND METHODS

General field operations. In 1987, field experiments were conducted at three sites in Manitoba: at Morden on a Hochfeld series clay loam (pH = 7.0); at Oak Bluff on a Red River clay (pH = 7.3); and at Portage la Prairie on a Neuhorst clay loam (pH = 7.4). In 1988, two field experiments were conducted at Oak Bluff and Portage la Prairie. The total plot area for each experiment was 800 to 900 m².

All sites selected in 1987 had been summerfallowed the previous year. The Morden site was irrigated with approximately 6 cm of water, one day prior to planting the crop. It also was the only site that had a naturally occurring mallow infestation. Mature mallow seed, collected from local sources and mechanically scarified¹, was spread at the other areas used in 1987. This seed was broadcast by hand, at rates of 50, 100 or 200 seed m⁻² in a predetermined pattern, and incorporated to a depth of 2.5 cm with a field cultivator. After cultivation, the area was harrowed twice. Certified Katepwa spring wheat seed was sown four to six days later at 100 kg ha⁻¹ using a double disk press drill. The seed was placed 4 to 5 cm deep in rows 15 cm apart at Portage la Prairie, and 17.5 cm apart at all other locations.

At the time of seeding, monoammonium phosphate (11-51-0) fertilizer at 100 kg ha⁻¹ was placed in the rows with the seed. The plots were seeded on May 15 at Morden, on May 25 at Portage la Prairie, and on June 1 at Oak Bluff. The mallow and wheat plants emerged nearly simultaneously in each trial except at the Morden site where the mallow began to emerge several days prior to the

¹Forsberg Sample Lot Scarifier, Forsbergs International Sales Corp., Thief River Falls, Minnesota, 56701.

crop. The percentage of added mallow seed which germinated and emerged was less than 7 and 11% at Portage la Prairie and Oak Bluff, respectively.

The 1988 trials, with the exception of one at Oak Bluff (1988₁), were conducted on land cropped in 1987. All sites in 1988 had natural infestations of mallow. Additional mallow seed was spread on the Portage la Prairie sites to supplement natural densities. Planting dates were May 11 (1988₁) and May 31 (1988₂) at Portage la Prairie, and May 18 for both sites at Oak Bluff (1988₁, 1988₂). All other procedures were the same as in 1987.

At the one to two leaf stage of the wheat crop, 0.75 m by 1.33 m (1.00 m²) permanent quadrats were established in pairs 0.5 m apart. Each site contained 27 to 30 pairs of quadrats with the exception of the 1988 Oak Bluff sites which had half that number. Quadrats were handweeded with one quadrat containing only wheat while the other quadrat contained wheat plus a known density of mallow plants. Each quadrat-pair was randomly located in the plot area. The two individual quadrats of a pair were laid end to end in the same orientation as the wheat rows, so that the same wheat rows were contained in each (Hume 1985). The crop density in each quadrat was determined.

Mallow seedlings in the 'weedy' quadrats were hand-thinned where necessary to achieve a wide variation of infestation levels. Also, where mallow seedlings emerged in groups from a common fruit, all seedlings but one were removed. Quadrats were maintained by hand-weeding periodically throughout the growing season. Densities of mallow in each quadrat were determined during quadrat establishment, at time of thinning, and, where possible, at crop

harvest. By late summer, disease caused by the fungal pathogen *Colletotrichum gloeosporioides* (Penz.) Sacc. f sp. *malvae*, reduced the mallow density of many plots in all trials.

Harvest procedures. At maturity, the wheat in each quadrat was cut at ground level and the number of wheat heads determined. The harvested material was air dried, threshed with a plot combine², and the seed and straw separated and weighed. Thousand kernel weights were determined using representative 200 and 500 kernel samples which had been allowed to reach near uniform moisture levels.

Statistical procedures. The initial statistical analysis was conducted using calculated differences in harvest data between quadrats within a pair (Hume 1985). In all cases, the value of a measured parameter from the "weedy" quadrat was subtracted from the corresponding "weed-free" quadrat value. Multiple linear regression analysis using a backward elimination, step-wise procedure (SAS V5) (Freund and Littell 1986) was performed using the difference between wheat grain yields as the dependent variable. The independent variables considered were the differences in mallow density, initial wheat population density, number of wheat heads at harvest, straw dry weight, and thousand kernel weight. The regression coefficients of each independent variable were determined by this procedure, with the variable that contributed the least to the fit of the regression model being deleted. The resulting equation was again examined with analysis ceasing when all remaining variables were statistically

²Hege Model 125B, Hans-Ulrich Hege, D-7112 Waldenburg, West Germany.

significant at the 0.05 level. These variables were then considered to contribute significantly to the model. Multiple and simple linear regression analysis procedures were also used specifically to determine if wheat yield differences between quadrats of a pair were related to mallow and/or wheat population densities.

The data were reorganized for analysis based upon a random survey design. The weed-free quadrats were randomly divided into four groups. Means were determined for each group to provide four values representative of weed-free conditions. These four values were included in a data set along with those from the quadrats containing both wheat and mallow. The statistical analyses described previously for the paired quadrat comparisons were repeated on this modified data set using the actual values of the measured parameters. In addition, using nonlinear regression procedures, the data were fitted to a nonlinear model (rectangular hyperbola) as suggested by Cousens (1985a; 1985b).

RESULTS AND DISCUSSION

The highest mallow densities at most sites used in this study were less than the anticipated range of up to 50 plants m^{-2} . The Portage 19882 site had a maximum mallow density of 33 plants m^{-2} while four other sites had maximum densities of less than 20 plants m^{-2} . Only the Morden site in 1987 with up to 97 plants m^{-2} , and the 19881 Portage site with densities as high as 237 plants m^{-2} , reached or surpassed the desired range of densities. Both sites had natural mallow infestations and soil moisture conditions favorable for early mallow seed germination.

Hume (1985) reported that weed-crop competition studies may provide inaccurate estimates of crop losses due to weeds if variations in crop density within an experiment are not taken into consideration. However, inclusion of crop density data in the current study had little effect upon the predictive power of the model for estimating wheat yield loss due to mallow interference. In addition, there was no significant relationship between final wheat seed yield and wheat densities over the range present in these trials. For example, wheat seed yield in the Portage 1988₁ experiment was not significantly affected over the range of 195 to 310 wheat plants m^{-2} in either the weedy or weed-free quadrats (Figure 1).

The influence of increasing densities of mallow on wheat seed yield was described by linear regression equations, with the data rearranged prior to analysis following a random survey design (Table 1). The results indicated significant wheat yield losses due to mallow interference occurred only in the Portage 1988₁ experiment. It can be calculated from the regression equation that each additional mallow plant caused an incremental wheat yield reduction of approximately 0.2 gram m^{-2} . A mallow density of 225 plants m^{-2} was associated with a wheat seed yield loss of approximately 13% in this experiment (Figure 2). The results of the Morden trial, where wheat yield losses did not occur, are representative of the other trials (Figure 3).

A rectangular hyperbolic model (Cousens 1985a), frequently used to describe crop losses caused by weed interference (O'Donovan 1988) did not fit the data. A linear function provided the best description of the relationship

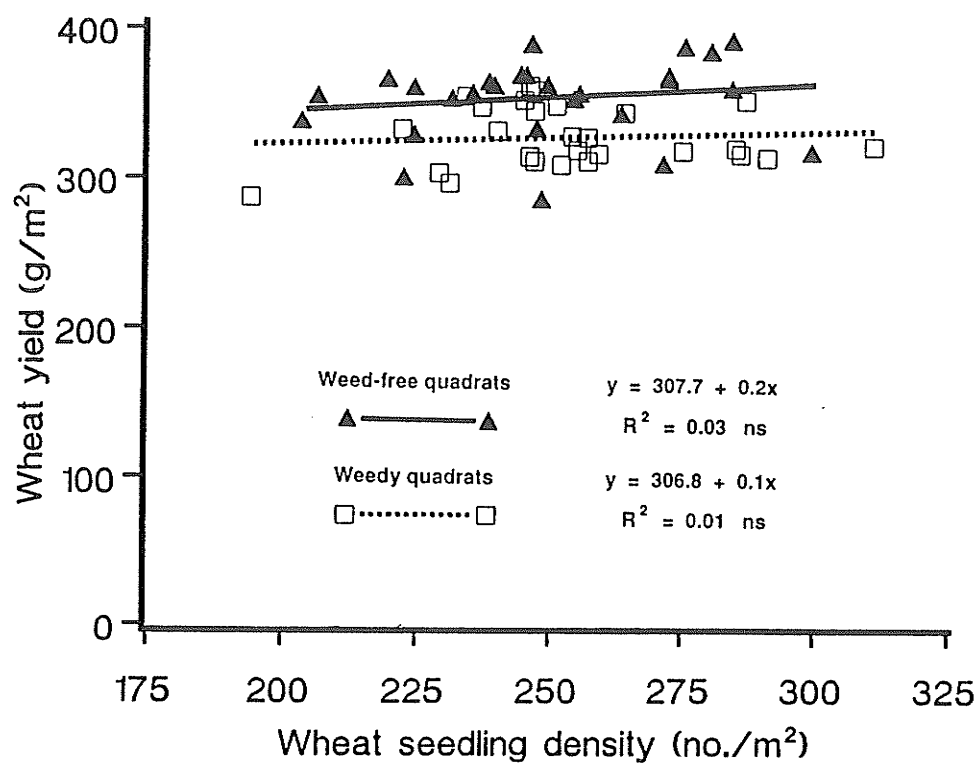


Figure 1. Relationship between wheat seed yield and wheat seedling density for the Portage 1988₁ experiment. Symbols represent individual 1 m² quadrats.

Table 1. Relationship between wheat grain yield in grams per m² (y) and the density of round-leaved mallow plants per m² at mid-June (x) following the model $y = b_0 + b_1x$ * (standard errors in parentheses).

Year	Location	b_0		b_1		R ²	Prob > F
1987	Morden	292.0	(6.3)	0.1	(0.1)	0.01	0.55
	Oak Bluff	229.5	(5.2)	-0.8	(0.6)	0.05	0.24
	Portage	289.8	(14.9)	2.6	(2.7)	0.03	0.34
1988	Portage						
	1988 ₁	346.1	(4.4)	-0.2	(0.05)	0.43	0.0001
	1988 ₂	211.9	(9.5)	-0.5	(0.7)	0.02	0.44
	Oak Bluff						
	1988 ₁	339.1	(11.9)	-0.1	(1.4)	0.001	0.93
	1988 ₂	181.2	(5.4)	-0.6	(0.5)	0.09	0.26

* b_0 is the intercept, b_1 is the linear regression coefficient, R² is the coefficient of determination, and Prob > F is the level of significance of the R² value which is a test of significance for the entire equation.

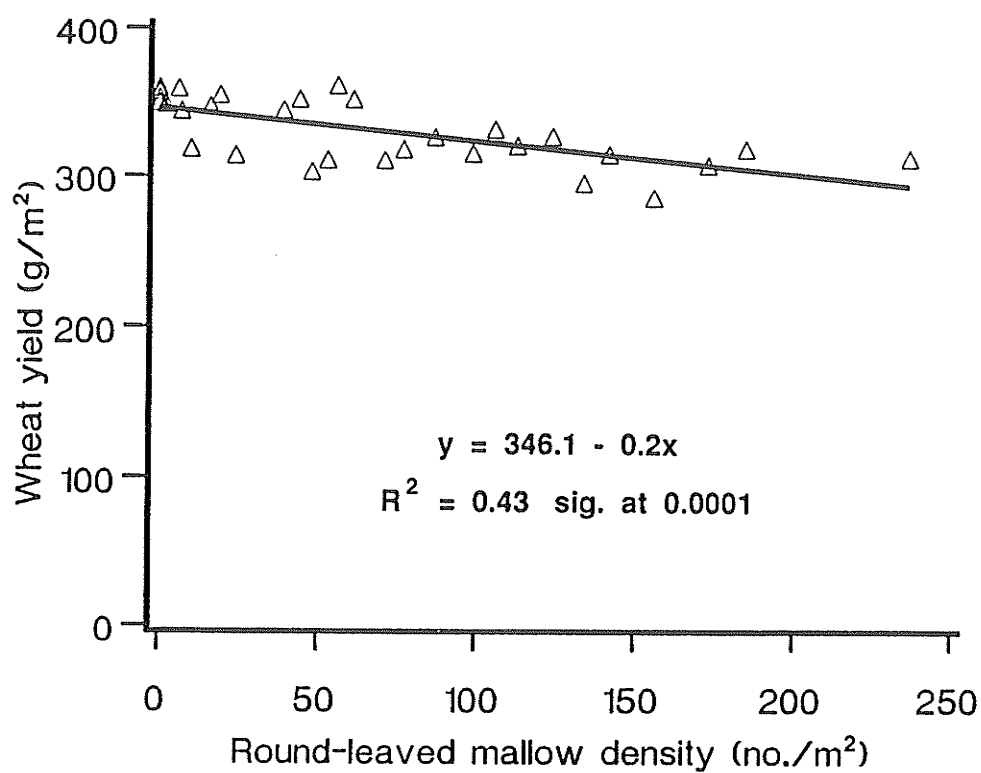


Figure 2. Relationship between wheat seed yield and round-leaved mallow density for the Portage 1988₁ experiment. Symbols represent individual 1 m² quadrat values.

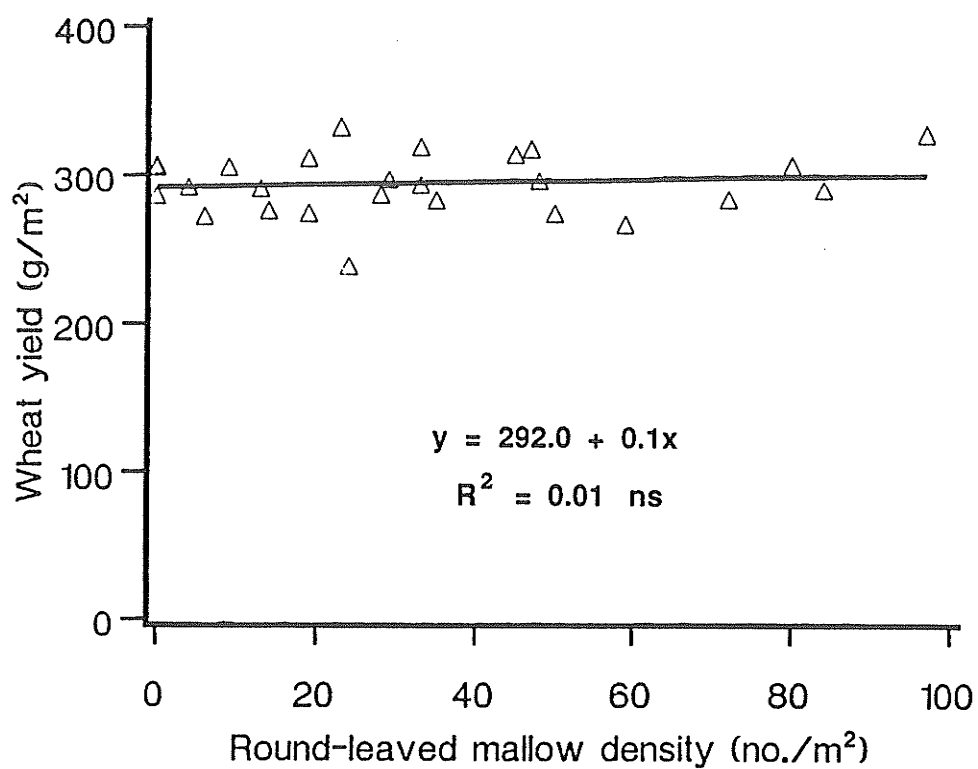


Figure 3. Relationship between wheat seed yield and round-leaved mallow density for the Morden experiment. Symbols represent individual 1 m² quadrat values.

between crop yield and mallow density over the range of mallow densities present in these trials.

A linear relationship with a negative slope between wheat head number at harvest and mallow density was significant at the $P = 0.01$ level for the Portage 1988₁ experiment (Figure 4). From the regression equation it can be calculated that at a mallow density of 225 plants m^{-2} , the number of wheat heads was reduced by approximately 14%. Thus, mallow interference reduced the number of wheat heads, and this reduction in head number could completely account for the associated reduction in wheat seed yield in this trial. This is consistent with the findings of Morishita and Thill (1988) in their study of wild oat (*Avena fatua*) interference on spring barley (*Hordeum vulgare*). They reported reductions in the number of tiller heads per barley plant only slightly less than reductions in grain yield.

Makowski (1987) reported decreases in wheat seedling populations due to high mallow seedling densities present prior to crop emergence. These decreases averaged 14 and 43% at sites with mean mallow densities of 139 and 338 plants m^{-2} , respectively. In the current study, wheat populations were not affected by the presence of mallow. Even in the Portage 1988₁ experiment, where the highest mallow populations occurred, the relationship between mallow densities averaging 70 plants m^{-2} and wheat seedling densities was not significant as determined by linear regression analysis (Figure 5).

Compared to the work of Makowski (1987), the current study involved lower mallow densities and a later mallow emergence date relative to the crop.

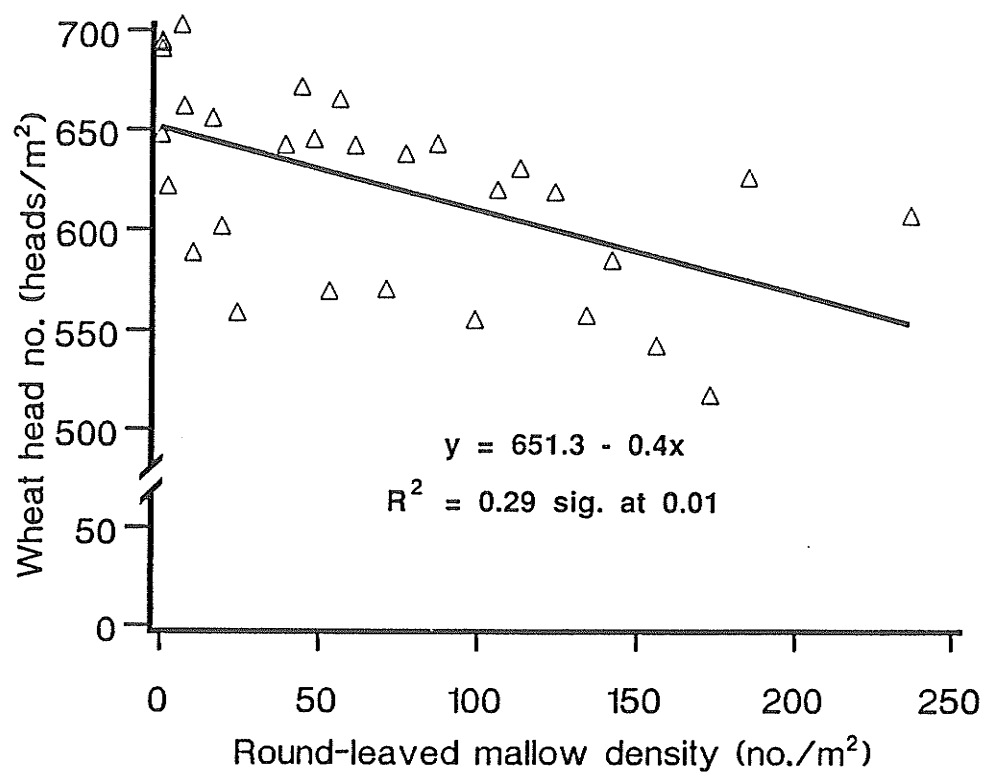


Figure 4. Relationship between wheat head number and round-leaved mallow density for the Portage 1988₁ experiment. Symbols represent individual 1 m² quadrat values.

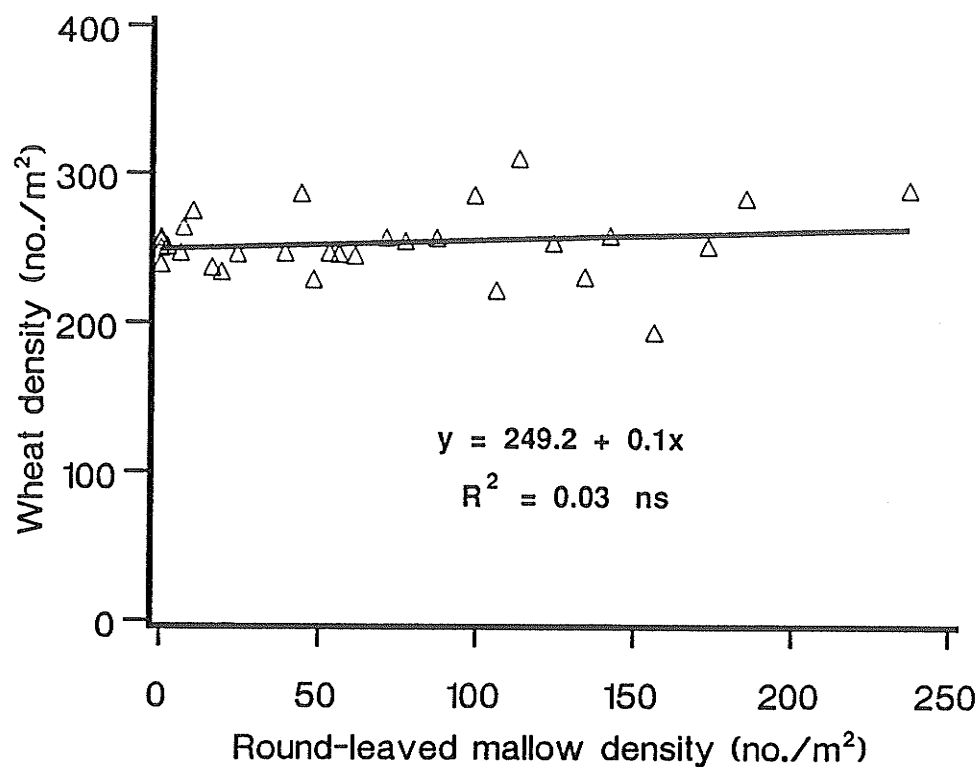


Figure 5. Relationship between wheat seedling density and round-leaved mallow density for the Portage 1988₁ experiment. Symbols represent individual 1 m² quadrat values.

Other differences included the locations and years in which the studies were conducted, as well as the corresponding environmental conditions.

The major difference in methodologies between the current study and that of Makowski (1987) was the drill row spacing. The uncommonly wide (23 to 30 cm) row spacings used by Makowski (1987) undoubtedly delayed and possibly prevented full closure of the wheat crop canopy. Light penetration into this canopy likely was higher than in a typical wheat field in Manitoba. As mallow growth is impeded by reduced light, mallow would be expected to have less effect on crop yields in Manitoba than was indicated by Makowski's results.

The results of the current study indicate significant wheat yield reductions due to mallow interference are not likely to occur at mallow densities common in Manitoba fields. However, mallow densities not expected to cause yield reductions in spring wheat have been demonstrated to cause substantial yield losses in less competitive crops such as flax and lentils (Budzinsky 1987; Makowski 1987). Makowski (1987) reported that the average shoot dry weight per mallow plant growing in wheat was only 20 to 30% that of the mallow plants growing in a lentil crop. These measurements were supported by visual observations of mallow growth in the two crops. In wheat, mallow plants were elongated with limited branching, while in lentils mallow plants had greater overall growth and branching (Makowski 1987). The superiority of wheat over less competitive crops such as flax and lentils in withstanding mallow interference can be attributed to the different effects these crops have on the growth of mallow plants.

The current study was successful in determining the effects of various densities of mallow on seed yields of spring wheat. There are, however, several changes in methodology the author would recommend for similar competition studies in the future. The paired-plot design and analysis proposed by Hume (1985) and employed in the current study, were found to be inappropriate and were subsequently abandoned. The data was then reanalyzed as a random survey design. This design is recommended over the paired-plot design as it requires approximately half the resources for a similar sized trial.

One aspect of mallow interference on spring wheat not addressed by the current study was the effect of mallow plants emerging before the crop. As O'Donovan et al. (1985) demonstrated with wild oat, the relative time of emergence of the weed species can influence its competitive effects on crop yields. Inclusion of interference trials with mallow emerging well ahead of the wheat in this study would have increased the accuracy with which wheat yield losses due to mallow could have been predicted in field situations.

Another change recommended would be to increase weed densities to a range sufficient for significant crop yield losses. In the current study, higher weed densities could have been achieved by increasing the mallow seeding rate, improving mallow germination rate through more efficient scarification, or by locating plots on land with well established mallow infestations.

It is important to have a thorough understanding of the growth and competitiveness of mallow for decisions regarding control of this weed. This study has dealt with the effects of mallow, at various densities, on the yield of

spring wheat. The following chapter describes a detailed study of the growth of mallow plants growing alone, within a spring wheat crop, and after the crop has been removed.

CHAPTER 3

GROWTH ANALYSIS OF ROUND-LEAVED MALLOW GROWN ALONE AND IN SPRING WHEAT

Abstract. The growth of mallow plants grown alone or within a wheat crop was examined in field trials conducted in 1987 and 1988 alongside the competition experiments at Portage la Prairie. Interference from spring wheat greatly impeded the growth of mallow plants. The maximum absolute growth rate of mallow plants was reduced by more than 99% by interference from spring wheat. By the eighth week after emergence, the average above ground biomass of mallow plants within the crop canopy was less than 3% that of plants growing alone. The total shoot dry weight of isolated mallow plants eventually exceeded 400 grams per plant. Lamina area was also greatly reduced by spring wheat interference. Mallow plants grown alone produced from 200 to 400 grams of flower and fruit dry matter per plant, with a calculated yield of 60,000 to 125,000 seeds. Spring wheat interference reduced mallow seed production to an average of 225 seeds per plant. Biomass partitioning, ie., percentage resource partitioning, into lamina, support, and reproductive structures was similar for plants growing alone and in a competitive environment. However, within the crop canopy, mallow grew more erect and branched less than in the absence of competition. Mallow plants regrowing after crop removal produced an additional 650 and 195 seeds per plant, on average, in 1987 and 1988, respectively.

Nomenclature: Round-leaved mallow, *Malva pusilla* (Sm.);
Spring wheat, *Triticum aestivum* 'Katepwa'.

Additional index words. Competition, growth analysis, logistic functions, biological models.

INTRODUCTION

As already described, mallow can cause substantial yield losses in crops such as flax and lentils while having less effect on the yield of a competitive crop such as spring wheat (Dew 1972) at the same mallow density (Budzinsky 1987; Makowski 1987). The minimal effect of mallow interference on wheat yields at mallow densities common in Manitoba fields was confirmed by the current study reported in chapter 2 (Nickel).

The morphology of individual mallow plants varies in response to the growing environment. In less competitive crops, the normally prostrate mallow plants grow more erect with their uppermost leaves usually above the crop canopy. In taller, more competitive crops, mallow plants are semi-erect with little branching and have reduced shoot biomass (Makowski 1987).

This study was conducted to a) explain previously observed minor reductions in spring wheat yields caused by mallow interference b) determine the effect of spring wheat interference on the growth and development of mallow, c) examine the effect of seeding date on mallow growth in the presence and absence of spring wheat interference, d) determine the seed production of mallow plants grown in isolation, in a wheat crop, and regrowing after the crop is harvested. Mathematical plant growth analysis techniques were used.

The functional (or regressional) approach to mathematical plant growth analysis using curves fitted to growth data was introduced by Vernon and Allison in 1963. The main group of equations used for this purpose since then have been polynomial exponential functions easily calculated via linear regression

(Elias and Causton 1976). These equations are used to accurately define the data and to smooth anomalous sampling results. The function parameters are not ascribed biological significance but comparative information is achieved using their derivatives (Hunt 1982).

Asymptotic non-linear equations also may be used for curve fitting in the functional approach to mathematical plant growth analysis (Causton and Venus 1981). More often, however, they serve as biological models of plant growth (Huett and O'Neill 1976; Fukai and Silsbury 1977; Silsbury *et al.* 1979). The parameters of these functions can be assigned biological meaning (Causton and Venus 1981). The logistic (or autocatalytic) function is the simplest asymptotic equation with a sigmoidal shape. It is symmetric about either side of a central inflection point. The logistic curve was selected for its simplicity and accuracy in describing the data.

MATERIALS AND METHODS

General field operations. Field experiments were conducted during 1987 and 1988 at Portage la Prairie, Manitoba. The soil is a Neuhorst clay loam (25% sand, 44% silt, and 31% clay) with a pH of 7.4 and 7.5% organic matter. The 1988 trial was situated on the same area used in 1987. This area was free of mallow and was summerfallowed in 1986.

Mallow seed was collected locally in the fall of 1986. Seed preparation involved the crushing of mature, air-dried seed capsules (fruits) and subsequent mechanical scarification of the seed. Mallow seed was broadcast by hand and incorporated to a depth of 2.5 cm with a field cultivator. Certified Katepwa spring

wheat seed was sown four to six days later at 100 kg ha^{-1} using a double disk press drill. The seed was placed 4 to 5 cm deep in rows 15 cm apart along with 100 kg ha^{-1} monoammonium phosphate (11-51-0). This procedure was repeated for a second seeding date in both 1987 and 1988. The earlier seeding date for both years was May 11 (1987₁ and 1988₁), while the latter date was May 25 in 1987 (1987₂) and May 31 in 1988 (1988₂).

One week after emergence, 300 mallow seedlings in each trial were selected at random and marked with survey flags. For half of these seedlings, all other plants within a 0.5 m radius were removed. The spring wheat stand was left surrounding the other 150 seedlings but all near-by weeds, including other mallow plants, were removed by hand.

Sampling Procedure. Destructive sampling of the marked mallow plants began one week after plant emergence (WAE). Each sample was comprised of ten randomly selected plants, cut at ground level. Sampling continued at weekly intervals until crop harvest for mallow plants growing with spring wheat. Mallow plants growing alone were sampled weekly for the first six weeks of growth. After the sixth week the number of these plants sampled was reduced to five per sampling date and the interval lengthened to three weeks. This was necessary because the plants became quite large and difficult to handle. Ten wheat plants were also sampled at each weekly sampling date. At maturity, the wheat crop was swathed approximately 20 cm above the ground. Sixty small or pruned mallow plants remaining in the stubble were then selected at random and marked in the earlier seeded trials (1987₁, 1988₁) in both years. Samples of ten of these plants were taken biweekly for eight weeks.

Each plant in a sample was separated into lamina, support (stems and petioles), and reproductive (flowers and fruits) components. Lamina areas were measured using a leaf area meter¹. Leaves that had been extensively damaged by disease or frost were not included in the determination of total lamina area. Dry weights were determined after the component parts were oven dried at 80 C for at least 24 hours.

A weekly estimate of crop leaf area index (LAI) was calculated from the measured lamina areas of ten randomly selected wheat plants from each experiment. These measurements were converted to a per area basis using the mean wheat population density determined for each experiment.

The number of seeds per gram of dried reproductive structures (flowers and fruits) was determined for the final samples of isolated plants in 1988. Groups of ten dried fruits and flowers were selected at random and crushed. Seeds which were completely formed and filled were considered viable and counted. Five such samples were taken from each of ten plants; hence there were 50 samples in total. Henceforth reproductive structures will be referred to only as 'fruits' unless it is necessary to distinguish between fruits and flowers.

Meteorological observations were recorded daily on-site² and were supplemented as required by data from a nearby weather station³. From these

¹Portable Leaf Area Meter, Model LI-3000, Li-Cor Inc., Lincoln, NE.

²Minimum Data Set Recording System, Model LI-1200S, Li-Cor Inc., Lincoln, NE.

³Canadian Forces Base, Portage la Prairie, Manitoba, R0M 1N0.

records weekly rainfall (mm week^{-1}) and integrated mean weekly temperatures (C) were determined (Figure 6.).

Photosynthetic photon flux density (PPFD) was measured using a 1 m-long line quantum sensor⁴ during the period 1200 hours to 1300 hours (DST) when plant samples were being collected. These readings were taken at three fixed locations per trial throughout the growing season, with the sensor placed between the crop rows at ground level. Near simultaneous readings were also taken above the crop canopy and were used in determining the fraction of incoming PPFD penetrating the crop canopy to ground level.

Statistical Analysis. Wherever possible, a logistic model was fitted to the primary (raw) data using a derivative-free non-linear regression procedure (PROC NLIN, METHOD=DUD, SAS V5) (Freund and Littell 1986). The model fitted was $y = a/(1 + be^{-cx})$ where "y" is the dependent variable (lamina area, component dry weight, etc.), "x" is the independent variable (weeks after emergence (WAE)), "e" is the base of the natural logarithm, and "a", "b", and "c" are nonlinear parameter estimates. For the logistic function, "a" is the estimated value of the upper asymptote, $a/(1 + b)$ is the y-axis intercept, $ac/4$ is the slope at the inflection point (maximum absolute growth rate (AGR_{max})), and $(\ln b)/c$ and $a/2$ are the values of "y" and "x" respectively at the inflection point (Figure 7). For the graphs, mean values for each sampling date were plotted, although not used in the regression procedure.

⁴Line Quantum Sensor, Model LI-191SB, Li-Cor Inc., Lincoln, NE.

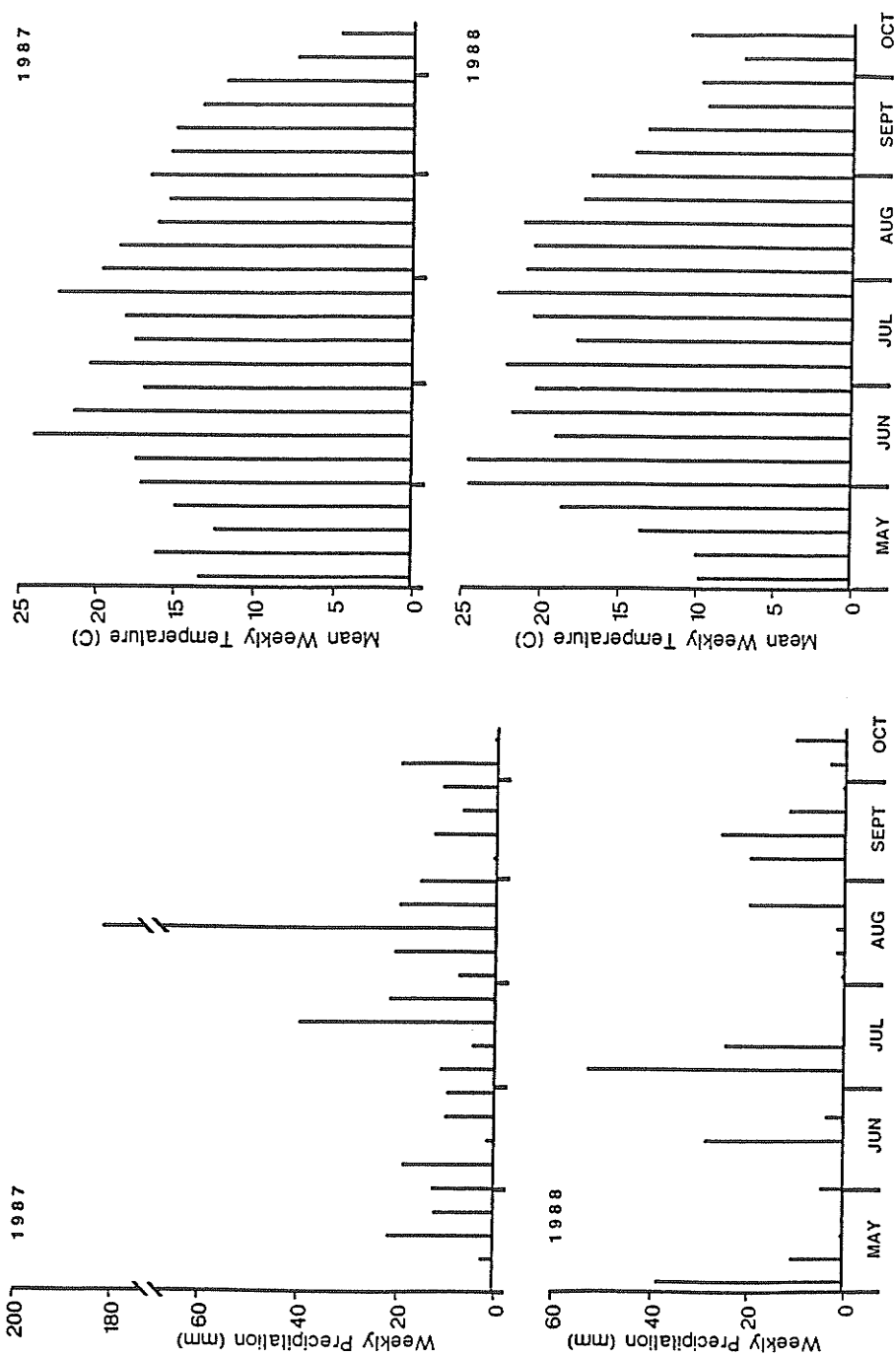


Figure 6. Precipitation and mean temperatures at Portage la Prairie during 1987 and 1988.

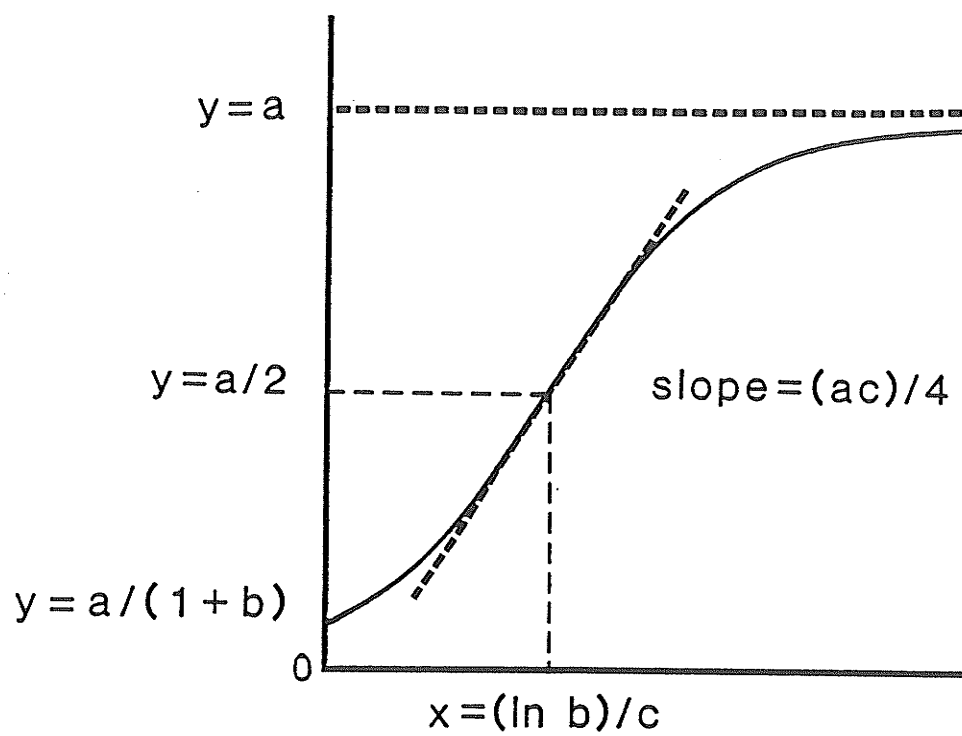


Figure 7. The logistic curve $y = \frac{a}{1 + be^{-cx}}$.

The coefficient of determination (R^2) was calculated as described by Kvalseth (1985). Parameter estimates were considered to be statistically significant at the 5% level where the standard error was less than half the value of the estimate (Koutsoyiannis 1977). Where the logistic model did not fit, a linear model was used, except for one instance where a quadratic model was required.

An unpaired T-test was used to distinguish differences in biomass partitioning between the two interference situations. Individual mean values from each of the trials were used in this calculation. Seed and fruit number estimates per gram dry weight of fruits were based on the determination of a grand sample mean, while the standard error of this mean was calculated using individual sample means.

RESULTS AND DISCUSSION

The logistic function was fitted to the growth analysis data to facilitate comparisons between mallow plants extremely different in size. The indeterminate growth habit of mallow could be described by this asymptotic function due to eventual environmental limitations on plant growth. These limitations were caused by seasonal changes and disease-induced senescence in general, or by crop interference locally.

Polynomial functions were also fitted to the data for comparison purposes. However, as these resulted in little or no improvement in the fit of the model, the logistic function was used for the reasons previously outlined.

In all trials there was near simultaneous emergence of mallow and wheat. The average wheat population densities in early and late May seeded trials, respectively, were 237.3 ± 18.4 and 209.8 ± 13.5 in 1987, and 253.7 ± 23.0 and 213.4 ± 15.9 in 1988.

Shoot dry weights. Shoot dry weights of mallow plants grown with or without interference from spring wheat are presented in Figure 8. In all trials, shoot dry weights of isolated mallow plants exceeded 400 g/plant. Plants emerging earlier in the season (1987₁, 1988₁) accumulated higher total shoot dry weights than those that emerged later (1987₂, 1988₂) (Figure 8; Table 2). The later-emerging plants were exposed to less favorable conditions due to seasonal weather changes during the final weeks of growth (Figure 6). This was particularly true during the last three weeks of growth in 1988 for mallow plants growing without interference (1988₂) where limited precipitation and lower temperatures resulted in reduced shoot growth (Figure 8).

The shoot dry weights of individual mallow plants grown with spring wheat varied widely as evidenced by low R² values for the fitted curves (Table 2). In 1987, for example, mallow shoot dry weights ranged from 0.29 to 2.11 g/plant over the ten plants sampled six WAE in the earlier seeded crop (1987₁). The variability in plant size reflected the range of interference levels provided by the crop. Larger mallow plants in the crop were located in areas of reduced interference, such as between crop rows or near a gap in the crop canopy. Although there was not a distinct seeding date effect, the greatest accumulation of shoot dry weight of plants grown with spring wheat interference was observed in the later seeded trial of 1988 (1988₂) (Table 2).

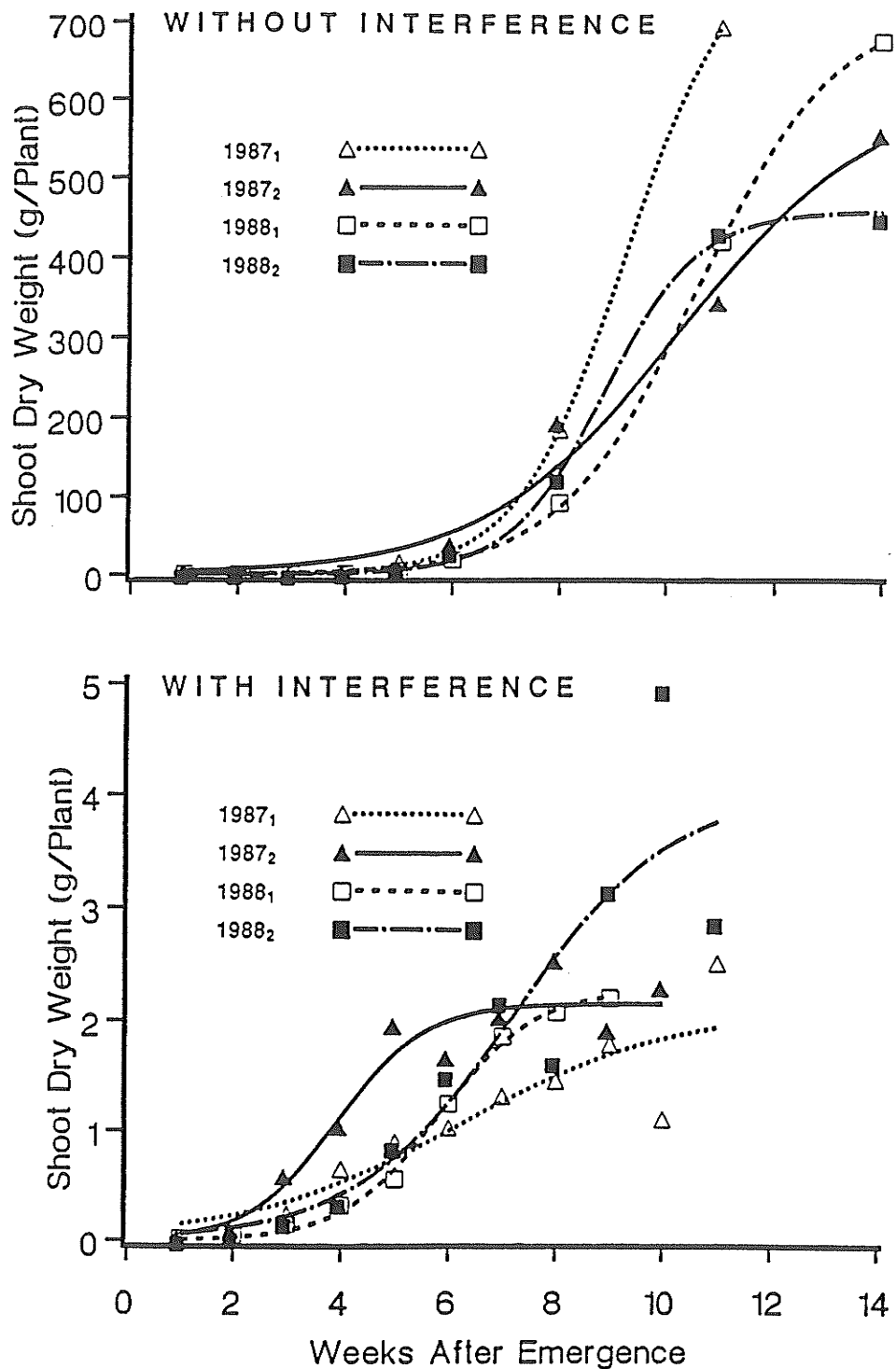


Figure 8. Effects of wheat interference on round-leaved mallow shoot dry weight accumulation. Mean values for each sampling date and the logistic function fitted to primary data are plotted for each experiment.

Table 2. Logistic equation parameter estimates (standard errors in parentheses) for round-leaved mallow shoot dry weight.

Expt.	a	b	c	R ²	ac/4	ln b/c
	(g)				(AGR max) (g/week)	(WAE)
WITHOUT INTERFERENCE						
1987 ₁	810 (86)	9745 (12906)	0.996 (0.184)	0.98	202	9.0
1987 ₂	614 (59)	266 (173)	0.546 (0.082)	0.89	84	10.0
1988 ₁	720 (38)	3565 (3434)	0.775 (0.099)	0.93	140	10.5
1988 ₂	458 (12)	22438 (23600)	1.137 (0.133)	0.97	130	9.0
WITH INTERFERENCE						
1987 ₁	2.12 (0.45)	22 (19)	0.500 (0.197)	0.37	0.265	6.0
1987 ₂	2.15 (0.15)	132 (225)	1.246 (0.447)	0.47	0.670	4.0
1988 ₁	2.28 (0.44)	701 (2312)	1.124 (0.625)	0.33	0.641	6.0
1988 ₂	4.05 (0.86)	131 (224)	0.680 (0.294)	0.37	0.689	7.0

By the eighth WAE, mallow plants growing with wheat had a dry weight only 0.8 to 2.4% that of plants growing without interference (Figure 8). The mallow plants in wheat were near their maximum dry weight at this time, while plants without interference were just beginning a period of exponential growth. Differences in the predicted asymptotes and time to inflection points reflect interference effects on shoot dry matter accumulation (Table 2). The predicted inflection point, also the point of maximum absolute growth rate (AGR max), occurred much later for mallow plants without interference (9 to 10.5 WAE) than for those with interference (4 to 7 WAE). The plants without interference had a predicted AGR max 100 to 700 times greater than those subjected to wheat interference.

Makowski (1987) determined that crop yield losses due to mallow interference were correlated with mallow biomass present at crop harvest and not mallow density. In the current study, the accumulation of shoot dry matter was substantially reduced by spring wheat interference. This extreme suppression of growth explains the observed relatively small crop yield reductions caused by mallow interference in competitive crops such as wheat (Makowski 1987; Nickel Chapter 2).

The logistic model also was used to describe the accumulation of wheat dry matter (Figure 9; Table 3). The problem of fitting an asymptotic curve to data from plants with a well defined weight loss at maturity (Hunt 1982) was avoided by restricting the sampling period to the first 11 weeks after plant emergence. Reductions in dry weight in 3 of 4 trials indicated senescence was beginning by

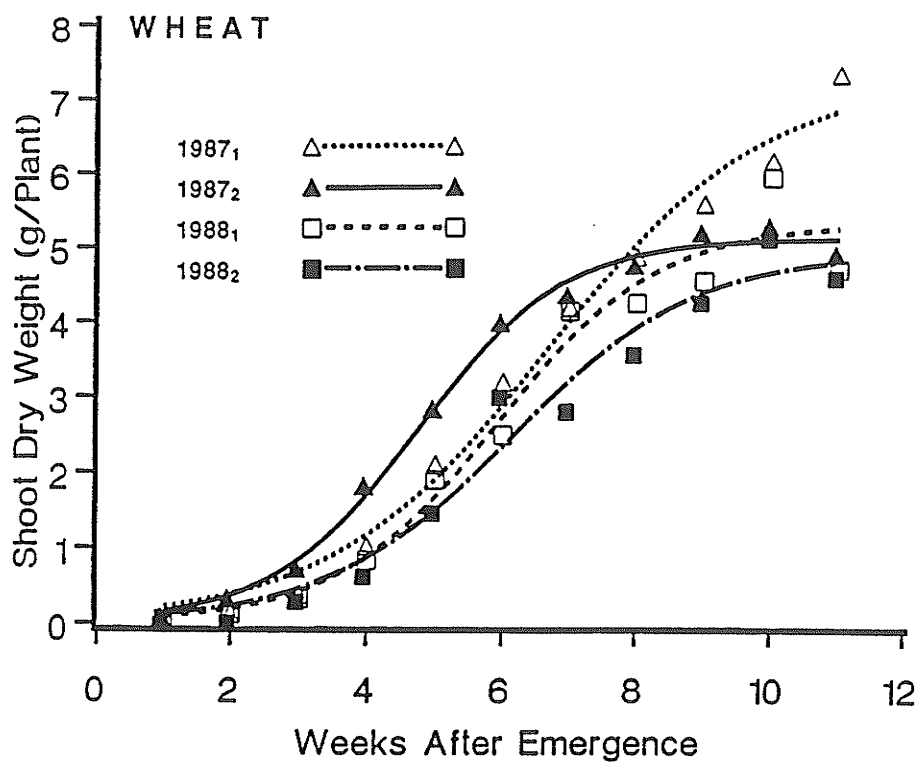


Figure 9. Accumulation of wheat shoot dry weight. Mean values for each sampling date and the logistic function fitted to primary data are plotted for each experiment.

Table 3. Estimated logistic equation parameters (standard errors in parentheses) for spring wheat shoot dry weight.

Expt.	a	b	c	R ²	ac/4	ln b/c
	(g)				(AGR max) (g/week)	(WAE)
1987 ₁	7.369 (0.516)	61.1 (27.7)	0.614 (0.087)	0.83	1.131	6.5
1987 ₂	5.148 (0.213)	81.6 (59.4)	0.928 (0.162)	0.75	1.194	4.5
1988 ₁	5.357 (0.323)	139.2 (111.3)	0.832 (0.151)	0.76	1.114	6.0
1988 ₂	4.974 (0.323)	84.2 (56.8)	0.721 (0.127)	0.76	0.897	6.0

the final sampling date. The logistic curve fitted the data well over this restricted period as evidenced by high R^2 values (Table 3).

Dry weight accumulation can be compared between wheat plants and neighboring mallow plants. It was the highest in the 1987₁ trial (Table 3) while the mallow plants in this trial had an AGR_{max} less than half that calculated for the other trials (Table 2). Similarly, in the 1988₂ trial, where growth of surrounding wheat was slowest (Table 3), the highest mallow shoot weights occurred (Table 2). Thus within the four trials, increased wheat growth corresponded with reduced mallow growth, and vice versa.

Dry weight increases were most rapid for both wheat and mallow in the 1987₂ trial (Table 2, Table 3). The AGR_{max} occurred 4 to 4.5 WAE in this trial as opposed to 6 to 7 WAE for all other trials. These growth analysis results confirmed visual observations. Both species grew rapidly with the mallow plants maintaining a plant height only slightly less than that of the crop for the first five weeks after plant emergence. This rapid shoot biomass accumulation by both species coincided with the most favorable growing conditions of the four trials.

Lamina area. Mallow plants growing without interference developed an extensive lamina area (Figure 10; Table 4). This was particularly true for plants in the 1987₁ trial where the average lamina area exceeded 2.5 m² per plant. The lamina area of mallow plants was greatly restricted by spring wheat interference. By the eighth week after emergence, plants growing with wheat had maximal lamina areas of 1.1 to 2.3% the lamina areas of plants of the same age without interference. Mallow plants without interference were at or near their

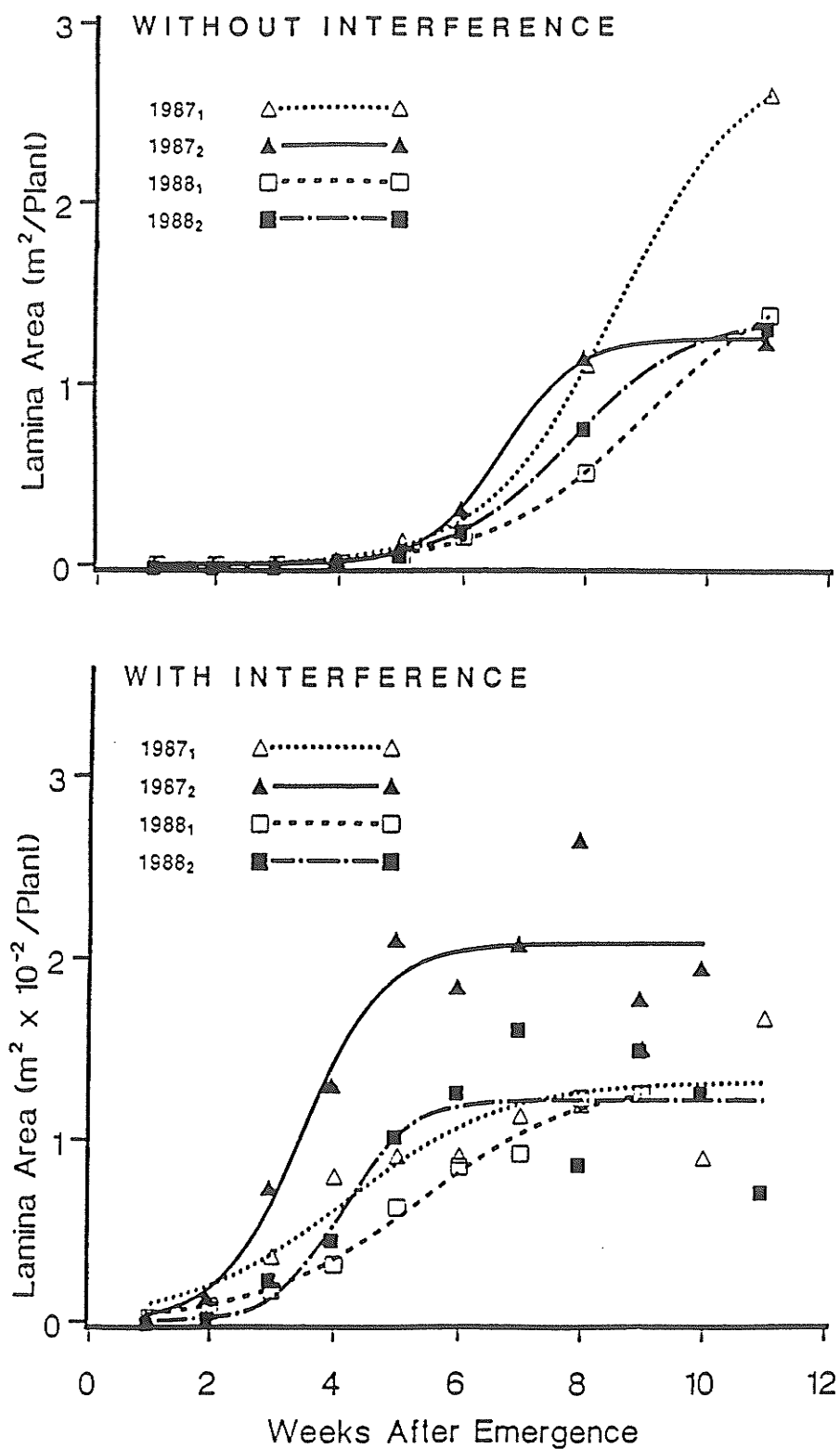


Figure 10. Effects of wheat interference on round-leaved mallow lamina area accumulation. Mean values for each sampling date and the logistic function fitted to primary data are plotted for each experiment.

Table 4. Estimated logistic equation parameters (standard errors in parentheses) for round-leaved mallow lamina area.

Expt.	a (m ²)	b	c	R ²	ac/4 (AGR max) (m ² /week)	ln b/c (WAE)
WITHOUT INTERFERENCE						
1987 ₁	2.831 (0.168)	2779 (2800)	0.935 (0.140)	0.95	0.662	8.5
1987 ₂	1.249 (0.070)	55517 (130720)	1.652 (0.393)	0.89	0.516	6.5
1988 ₁	1.635 (0.175)	1432 (1151)	0.812 (0.125)	0.93	0.332	9.0
1988 ₂	1.365 (0.023)	3040 (894)	1.037 (0.043)	0.99	0.354	7.5
WITH INTERFERENCE						
1987 ₁	0.0132 (0.0011)	29 (29)	0.800 (0.262)	0.42	0.00264	4.0
1987 ₂	0.0208 (0.0013)	244 (501)	1.577 (0.595)	0.48	0.00820	3.5
1988 ₁	0.0132 (0.0028)	65 (101)	0.777 (0.366)	0.34	0.00256	5.5
1988 ₂	0.0122 (0.0011)	2533 (7894)	1.897 (0.896)	0.29	0.00579	4.0

maximum rate of lamina area increase (AGR_{max}) (Table 4) at this time with the difference in lamina areas between interference conditions becoming even greater after this point.

The AGR_{max} of lamina area for plants growing without interference was much higher for both seeding dates during 1987 than during 1988 (Table 4). The development of lamina area was undoubtedly affected by limited precipitation and high temperatures in 1988 (Figure 6). Restricted lamina area expansion is a well known plant response to high temperatures and limited moisture. A wide variation in lamina areas occurred for plants growing in wheat, particularly in the 1988 season. As was the case for shoot dry weights, this was reflected in the relatively low R^2 values for the fitted curves. The AGR_{max} for mallow lamina area was attained more quickly in the later seeded trials (Table 4). This was expected as environmental conditions most favorable for rapid plant growth occurred relatively early in the development period of these plants.

The mallow plants without interference had a predicted AGR_{max} 60 to 250 times greater than those subjected to wheat interference.

Lamina areas of mallow plants growing in spring wheat can be compared to the leaf area index (LAI) of the surrounding wheat canopy (Figure 11.1). The conditions within the crop canopy varied between years. The maximum LAI of the crop was much greater and sustained longer in 1987. Canopy closure of the spring wheat crop in 1988 was not as complete, allowing greater light penetration to the ground (Figure 11.2). The mallow plants growing within the crop in 1988

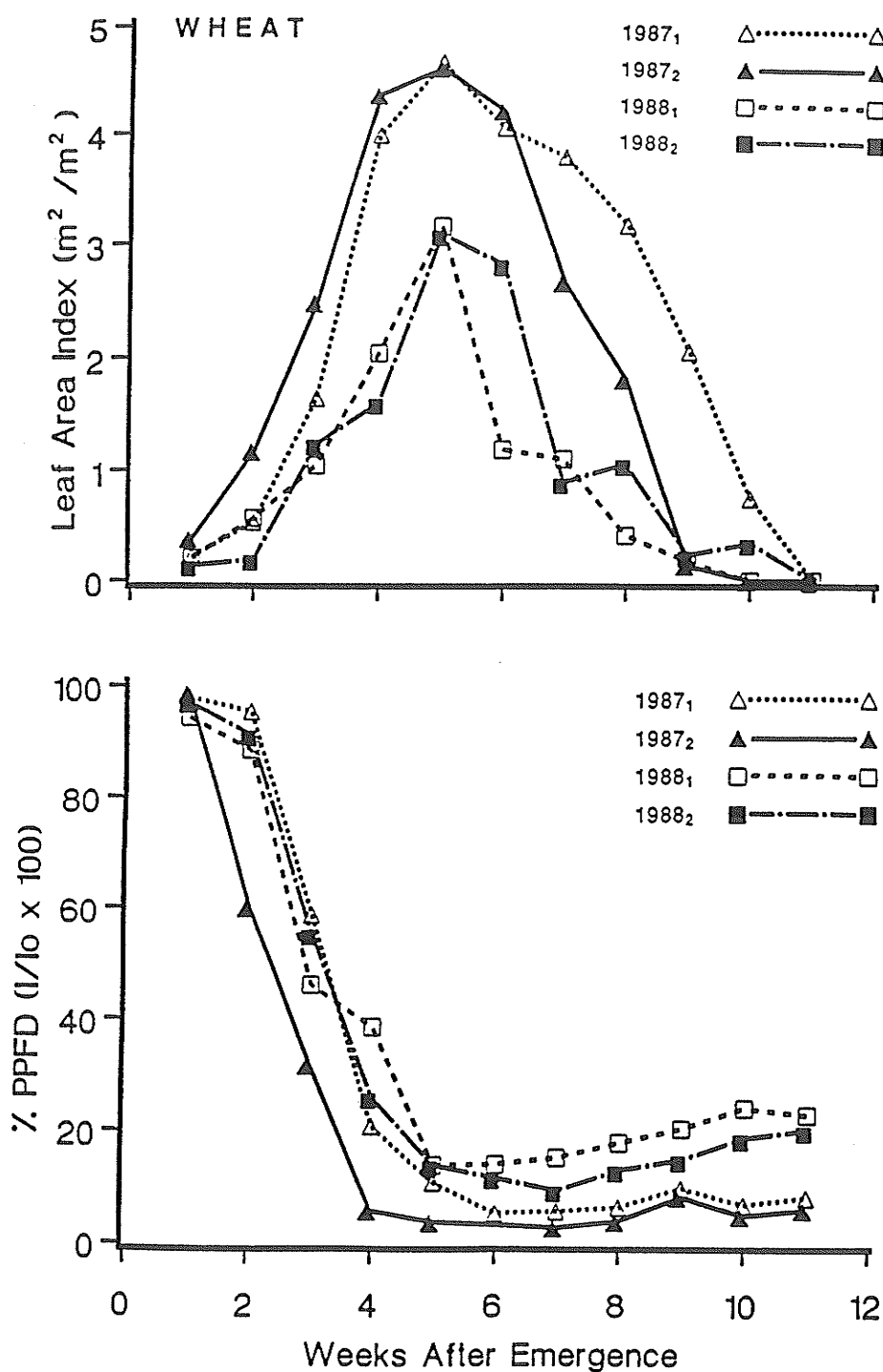


Figure 11.1 Accumulation of wheat lamina area per unit ground area. Mean LAI values per sampling date are plotted and connected for each experiment.

Figure 11.2 Percent of incipient (I_0) photosynthetic photon flux density (PPFD) 400 to 700 nm wavelength light penetrating the crop canopy to the ground (I). Mean percent penetration values per sampling date are plotted and connected for each experiment.

had the higher light levels offset by other environmental stresses resulting in similar lamina areas as in 1987.

In response to favorable conditions, both the 1987₂ spring wheat crop and the plants growing within it experienced rapid lamina area development similar to that discussed previously for shoot growth.

Fruit dry weight. The logistic function was fitted to fruit (reproductive structure) dry weight data from mallow plants without wheat interference (Figure 12; Table 5). The function described the data well, although an upper asymptote due to a decreased rate of dry matter accumulation was strongly indicated only by the data from the 1988₂ trial. Fruit dry weight accumulation by mallow plants in trials seeded in early May was greater than in those seeded later in the season. This is especially evident when comparing the predicted values of the upper asymptotes for the 1988 trials (Table 5). The upper asymptote in the 1987₁ trial clearly is a predicted value, due to lack of a final sampling date as a result of severe disease damage. The effect of seeding date was similar to that for the shoot dry weight data and can again be explained by differences in growing conditions. The maximum rate of mallow fruit dry weight accumulation occurred 9.5 to 12.5 WAE in these trials.

Fruit dry weight production by mallow plants growing with wheat varied greatly, both between plants sampled at a specific date and between sampling dates (Figure 12). A linear function was used as the logistic function did not fit this data. The linear function also fit rather poorly, as evidenced by low R^2 values (Table 5), due to this wide variation in fruit dry weight production.

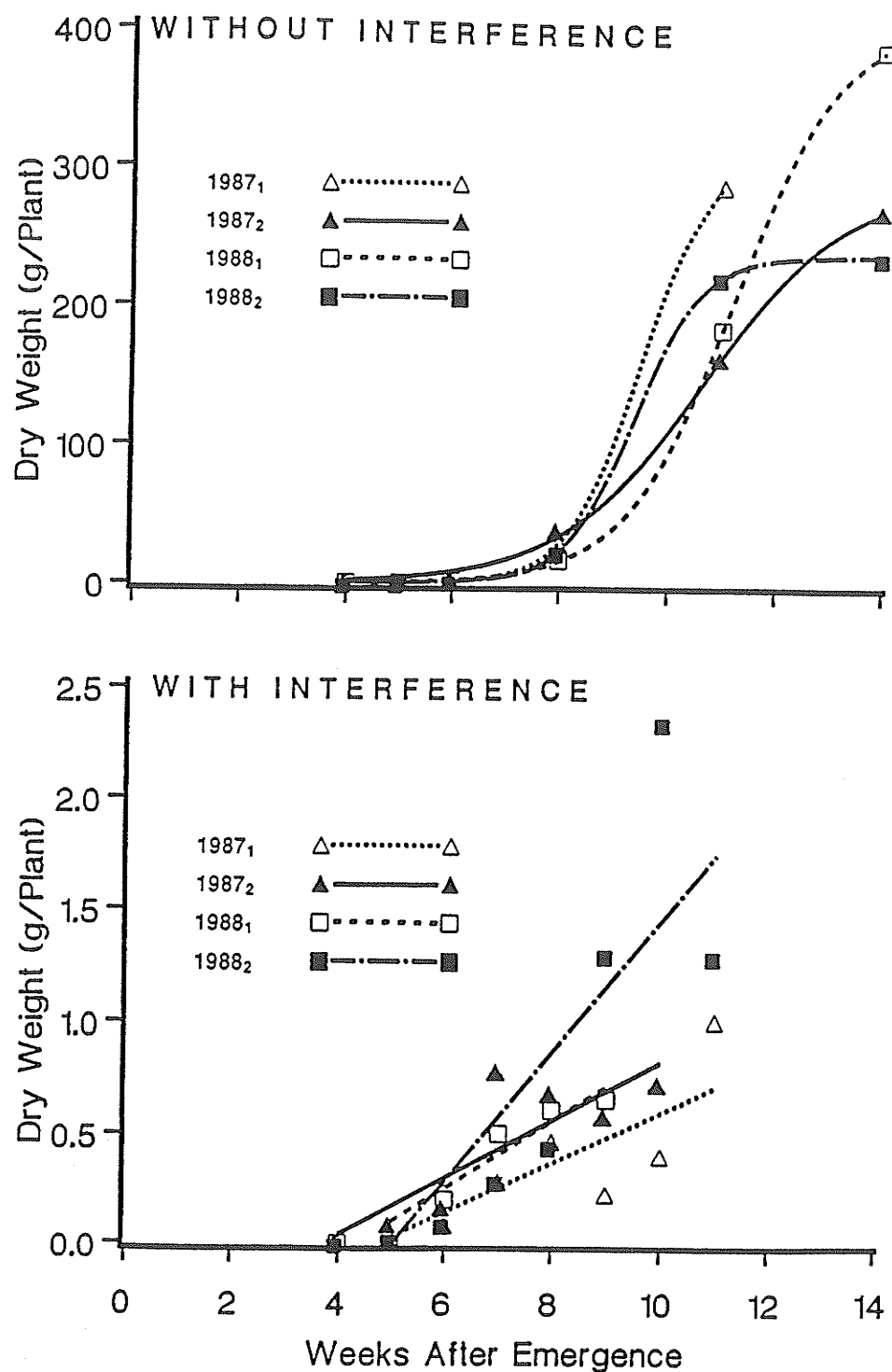


Figure 12. Effects of wheat interference on round-leaved mallow flower and fruit dry weight accumulation. Mean values for each sampling date and logistic or linear functions fitted to primary data are plotted for each experiment.

Table 5. Logistic and linear equation parameter estimates (standard errors in parentheses) for round-leaved mallow flower and fruit dry weight.

WITHOUT INTERFERENCE (logistic equations)						
Expt.	a	b	c	R ²	ac/4	ln b/c
	(g)				(AGR max) (WAE) (g/week)	
1987 ₁	314 (146)	2.5 x 10 ⁶ (3.2 x 10 ⁷)	1.553 (1.648)	0.98	122	9.5
1987 ₂	290 (23)	3193 (4681)	0.756 (0.150)	0.89	55	10.5
1988 ₁	407 (28)	77885 (2.4 x 10 ⁵)	1.005 (0.288)	0.93	102	12.5
1988 ₂	235 (6)	4.3 x 10 ⁶ (7.7 x 10 ⁶)	1.632 (0.207)	0.97	95	9.5

WITH INTERFERENCE (Linear equations)			
Expt.	j	k	R ²
1987 ₁	-0.536 (0.147)	0.113 (0.018)	0.31
1987 ₂	-0.480 (0.190)	0.130 (0.026)	0.28
1988 ₁	-0.664 (0.230)	0.153 (0.034)	0.26
1988 ₂	-1.462 (0.375)	0.291 (0.048)	0.32

However, it is apparent that mallow plants in the 1988₂ trial had the greatest fruit dry weight accumulation.

The predicted fruit dry weight accumulation by mallow plants in the different trials were compared at 10 weeks after plant emergence. This date corresponded with the average time of the maximum rate of fruit dry weight accumulation (AGR_{max}) for the mallow plants without interference, and near maximum total fruit dry weight accumulation for those plants with crop interference. At this date, fruit dry weights of mallow plants with interference were less than 1% of plants without interference. Furthermore, this comparison was made at a time when the isolated plants had accumulated only half the total fruit dry weight predicted by the logistic function (ie. at the inflection point). Thus, mallow fruit production is extremely inhibited by wheat interference.

Biomass partitioning. The general pattern of mallow biomass partitioning was affected only slightly by competition (Figure 13). However, significant differences in partitioning between mallow plants with and without interference were observed during certain periods of plant development. The lamina portion of the total shoot dry weight (leaf weight ratio) was significantly greater ($P=0.05$) for the plants without competition from 4 to 8 WAE. This coincided with mallow plants in the crop having a significantly greater proportion of shoot dry weight in stems and petioles from 4 to 5 WAE, and in flowers and fruits from 7 to 8 WAE.

The biomass partitioning results (Figure 13) supported visual observations of plant morphology. Mallow plants without crop interference grew in a prostrate manner covering a large area, with the lamina area oriented to minimize mutual

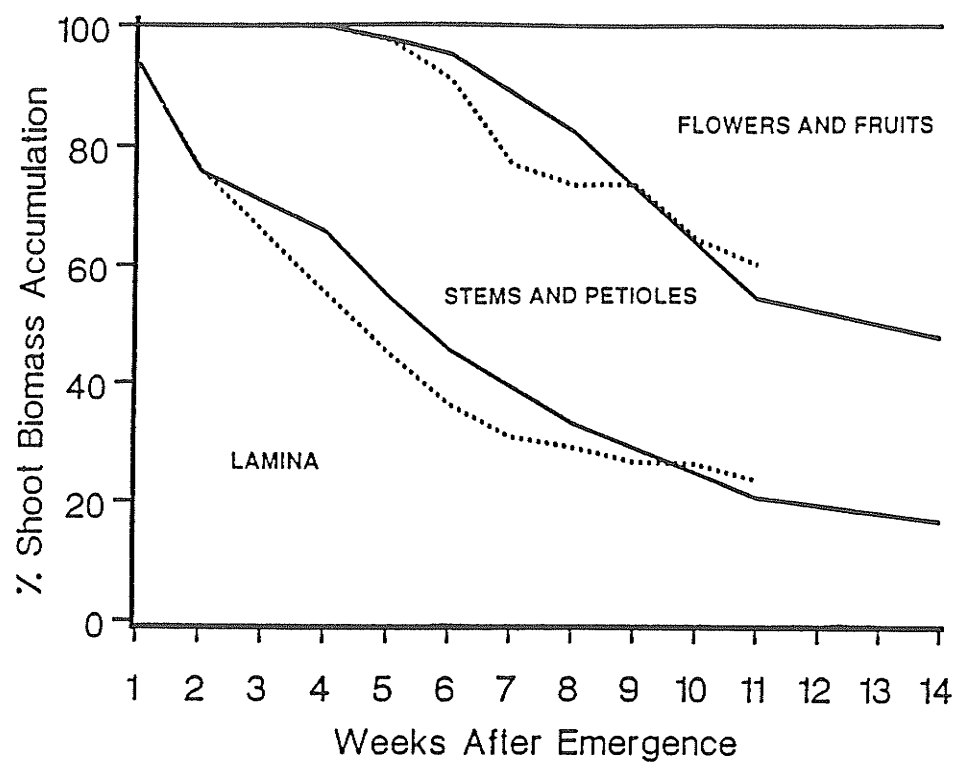


Figure 13. Effects of wheat interference on the partitioning of round-leaved mallow shoot biomass. The broken lines represent mean values from round-leaved mallow plants grown with wheat interference, while the solid lines represent mean values from round-leaved mallow plants grown without interference.

shading. Mallow plants with crop interference grew more erectly shortly after emergence. In response to wheat interference, mallow produced most of its leaves near the top of the plant, in the upper one-third region of the crop canopy. This response was similar to that documented by Regnier and Stoller (1989) for velvetleaf, another member of the Malvaceae family. Thus, an increased proportion of the shoot biomass was located in the support material (stems and petioles) required to place lamina in these elevated positions.

The relatively early allocation of dry weight into flowers and fruits by mallow plants growing with interference may be a result of the early cessation of exponential growth by other plant components. For example, lamina area expansion had virtually ceased seven weeks after plant emergence for mallow plants grown in the crop (Figure 10). It is possible that the earlier favoring of reproductive structures in shoot dry weight partitioning is an evolved survival response to interference.

Seed production. It was determined that near the end of the growing season, one gram of mallow reproductive structures consisted of 38.0 (5.2) flowers and fruits, and 325.6 (27.9) seeds (standard errors in parentheses). Mallow plants grown without interference produced in excess of 200 grams of fruit dry weight in each trial (Figure 12), thus, the estimated seed production exceeded 60,000 seeds per plant. The greatest fruit production occurred in the 1988₁ trial. The average fruit dry weight of 384 grams for the final sampling date represented approximately 125,000 seeds per plant.

Mallow plants grown with wheat interference had an average fruit dry weight accumulation of slightly more than 0.7 grams with an estimated seed production of 225 seeds per plant. Thus, interference from wheat reduced potential mallow seed production by 99.5%. The mallow seed produced within a crop, however, could contaminate the harvested grain or replace and increase soil seed reserves. Minimizing the amount of mallow seed returned to the soil is important particularly when less competitive crops such as flax and lentils are included in crop rotations on mallow-infested land (Makowski and Morrison, 1989).

Regrowth. The regrowth of mallow plants after the crop is removed (swathed) can be important in a field situation. After the trials seeded in early May were swathed, the mallow plants remaining in the field had shoot dry weights of less than one gram per plant (Figure 14; Table 6). The degree of regrowth by these plants was dependent upon environmental conditions. In 1987, a 25-fold increase in shoot dry weight to approximately 25 grams per plant occurred due to favorable conditions. Extremely dry conditions in 1988 restricted the shoot dry weight increase to only 2.5-fold over the 8 week period following swathing.

Carlson and Eberlein (1983) reported that *M. rotundifolia* (a commonly used synonym for *M. pusilla*) did not produce additional seed during regrowth following wheat harvest. In contrast, mallow fruit dry weights in the current experiments increased by more than 2.0 grams per plant following swathing in 1987, and by 0.6 grams in 1988. Examination of these fruits indicated similar seed numbers per gram of fruits as those produced by the mallow plants grown without competition. Thus, an average of 650 and 195 additional seeds per plant

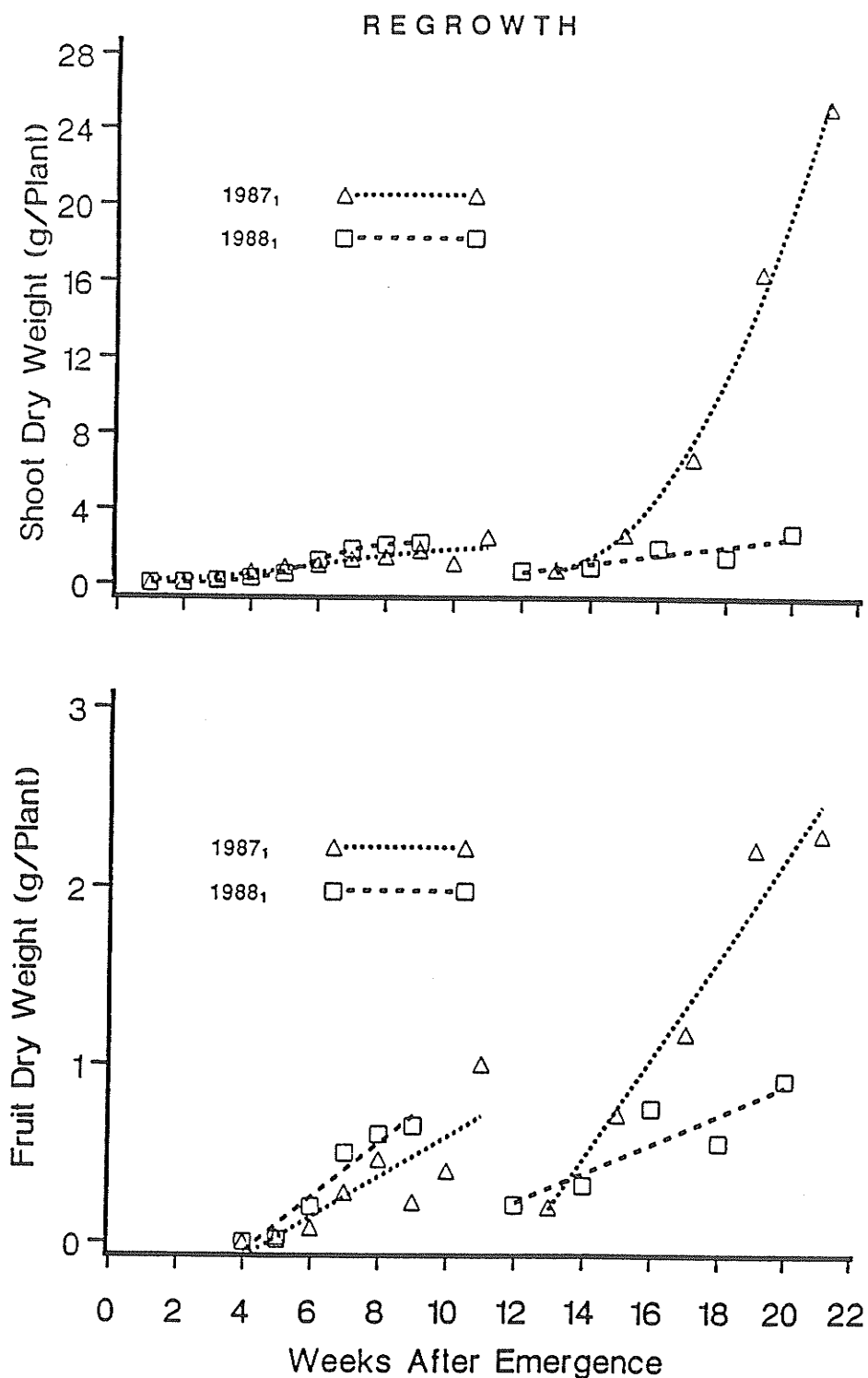


Figure 14. Accumulation of round-leaved mallow shoot dry weight and flower and fruit dry weight as affected by swathing the crop. Mean values for each sampling date and logistic, linear, or quadratic functions fitted to primary data are plotted for each experiment.

Table 6. Linear and quadratic equation parameter estimates (standard errors in parentheses) for round-leaved mallow regrowth after crop removal.

Year	j	k	l	R ²
SHOOT DRY WEIGHT				
1987 ₁	54.846 (64.464)	-8.693 (7.738)	0.348 (0.227)	0.44
1988 ₁	-2.202 (0.780)	0.234 (0.048)		0.35
FLOWER AND FRUIT DRY WEIGHT				
1987 ₁	-3.505 (1.499)	0.284 (0.087)		0.18
1988 ₁	-0.758 (0.356)	0.082 (0.022)		0.23

were produced during the eight week regrowth period in 1987 and 1988, respectively.

SUMMARY

The growth of mallow was greatly suppressed, approximately 98%, by spring wheat interference. Mallow plants growing with wheat were not able to position their leaves above the crop canopy. Therefore, the growth of these plants was virtually arrested by mid-season due to shading and other interference effects. The degree of interference was not related to the emergence date of the crop.

Mallow plants are able to produce extremely large amounts of seed when grown without crop interference. Interference from a spring wheat crop severely restricted this seed production, although regrowth of mallow plants following crop removal can result in additional seed production exceeding that produced prior to crop harvest.

The current study was unconventional in its approach to plant growth analysis as it involved the logistic function as a biological model. This approach allowed description and comparison of plant growth among very different sized plants. Use of this approach was appropriate as it facilitated all of the objectives of the study.

The results of this study are important to the understanding of previous mallow interference studies. The minimal spring wheat yield reductions at high mallow densities, recorded in the interference study described earlier, can be

understood in light of the extreme interference effects on mallow measured in the current study. The potential growth of mallow plants without interference demonstrates the importance of crop interference in limiting the competitive effects of this weed. Less competitive crops such as flax and lentils permit mallow plants to grow larger and have greater effect on crop yield (Budzinsky 1987; Makowski 1987).

The potential seed production by mallow plants within the crop, and after the crop is removed, could influence management decisions concerning a field. Mallow densities in wheat may not warrant control based solely on expected yield losses, but may when the potential mallow seed production is included in the calculation. Minimizing the amount of mallow seed produced and returned to the soil would be an important consideration if the field was used to grow crops more susceptible to mallow interference.

The current study examined interspecific interference effects on individual mallow plants within a spring wheat crop. Interference effects from other mallow plants (intraspecific interference) were deliberately avoided. However, to fully analyze the growth of mallow plants in field situations, measurement of intraspecific interference should be included. While quantifying intraspecific interference effects in mallow would have made the current study more complete, it was beyond the scope of this study.

The author would recommend several changes for similar growth analysis studies in the future. The sampling of large plants should have occurred more often but involved fewer plants per sample. A two week interval between

samples would have provided a more continuous set of measurements when growth was most rapid. Taking only three plants per sample would offset the work required for the increased number of samples while only slightly increasing the risk of sample results being distorted by plants of exceptional size within a sample.

The main change proposed for the analysis of the data would be to use the Richard's function rather than the logistic function. The variable inflection point could be valuable in fitting data more accurately although direct comparisons between curves would become more difficult.

There are few examples in the literature of studies which have included both interference and growth analysis components. The main benefit of adding plant growth analysis to interference studies would be a more complete understanding of the effects of interference on the growth and development of the plants involved. This understanding would be useful in management decisions aimed at providing a competitive advantage to the desired species.

CHAPTER 4

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