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Title: Weed Suppression in Vegetables with Residues of 'Micah' Barley (*Hordeum vulgare* L.) and Other Spring Cereals.

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Three experiments whose objectives were to investigate cover crop kill by winter freeze, weed suppression by 'Micah' barley and other spring cereals, and allelopathic potential of cereal covers were conducted at the Vegetable Research Farm and in the greenhouse and growth chamber facilities at OSU in 1989/90. Kill by winter freeze failed under the warm winter of Corvallis in 1989/90. Complementary usage of herbicides and residues for weed control is suggested.

Residues of herbicide killed 'Micah' barley suppressed (79-88%) weed emergence and growth for up to six weeks in tomatoes, lettuce and cucumber. Allelopathy, besides physical effects of the mulch, contributed to weed control in the system. Greenhouse and growth chamber bioassay studies confirmed the presence of seed germination inhibitors in residues of 'Micah' barley and other covers.

No differences in yield among treatments were observed for each crop when weeds were controlled six weeks after planting.

Weed Suppression in Vegetables With Residues of 'Micah' Barley (*Hordeum vulgare* L.) and Other Spring Cereals

by

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INTRODUCTION

Weeds have been a problem for humans since they first attempted to grow crops for food (Holm, 1969; Vega, 1983). Weeds reduce crop yields through competition for mineral nutrients, water and light (Hager, 1980; Harper, 1971; Putnam and DeFrank, 1983; Vega, 1983; Radosevich and Holt, 1984); interfere with growth, germination and metabolism by adding toxic chemicals to the environment (Putnam, 1979, 1988 and 1990; Putnam and DeFrank, 1983; Radosevich and Holt, 1984) interfere with operations such as planting, cultivation and harvesting through contaminants (Akobundu, 1983; Koch et al., 1983 and Patriquin, 1987); and hosting pests and contributing to diseases (William, 1981; Lerch and Zemp, 1983; Almeida, 1985). Weeds also influence the types of crops and season for crop production. In Malawi, for example, vegetable growing is largely a dry-season activity (April-September) because fewer pests and labor conflicts occur at this time compared to when rain-fed crops are grown.

In spite of the many weed control options available, practices center on manual, mechanical and chemical methods. These represent costly control methods. Manual practices in particular, are burdensome and inefficient. Burrill et al. (1988) indicated that the most effective and least expensive way to control weeds is to combine two or more methods.

Chilanga (1987) revealed, through an informal survey conducted among smallholder vegetable growers in Malawi, that costs were a major limitation in adopting the high input technologies developed by researchers. In fact, growers were modifying these to suit their circumstances. The need to explore other complementary weed control options cannot be overemphasized.

Cover cropping is an old practice (Jones, 1972; Putnam, 1990) that involves the growing of a crop (leguminous or non-leguminous) primarily for soil cover to prevent or reduce soil erosion (Akobundu, 1984). Its other attributes include: increasing soil organic matter content, conserving soil moisture, reducing costs related to acquisition of mulching materials, transportation and application; and controlling weeds. The practice is popular in orchard (Hogue and Neilsen, 1989) and plantation (Soong and Yap, 1976) crops. Vegetables have also responded favorably (Adams et al., 1970; Wilson, 1978; Box et al., 1980; Chen et al., 1989; Miller et al., 1989). A survey conducted by Yost and Evans (1988) involving green manure/cover crop use by farmers in Africa, Asia, Latin America and Oceania revealed that its popularity was negligible. William (1989), however, suggested that annual cover crops along with appropriate management strategies have the potential to enhance horticultural cropping systems and minimize adverse effects on the soil.

The use of a cover crop to complement other weed control efforts has the advantage of timeliness and reducing labor conflicts that occur in multiple cropping enterprises common especially among smallholders. Zimdahl (1980) reported that weed-free conditions in the first one-third of the crop cycle were essential in minimizing crop losses. Covers might provide this protection while also allowing growers time to weed other priority crops. William et al., (1988) noted from an informal survey conducted in Malawi that smallholders weeded their maize fields before turning to other crops thereby delaying or reducing vegetable harvests.

Research conducted in Michigan and North Carolina has indicated that cover crops of cereal grains can suppress weeds in succeeding or companion crops in no-tillage systems (Fay and Duke, 1977; Putnam and Duke, 1978; Putnam and DeFrank, 1979 and 1983; Putnam, 1987). Information, however, is lacking on the small grain crops of Oregon. This study was designed to investigate cover crop kill by winter freeze, weed suppression in vegetables using 'Micah' barley residues and other spring cereals, and to assess the allelopathic potential of all cover crops.

LITERATURE REVIEW

Weed Control

Weeds reduce crop yields, cause human drudgery and are costly to control. Vegetable crop losses from weed competition vary depending on the species and environmental conditions. Total crop loss can occur when weeds compete during the entire crop life cycle. Roberts et al., (1977), reported complete loss of marketable yield of lettuce (Lactuca sativa L.) from annual weeds at densities of 65 to 315/m^2. William and Warren (1975) reported the following crop losses in some vegetables due to season-long purple nutsedge (Cyperus rotundus L.) competition: garlic (Allium sativum L.) 89%, okra (Abelmoschus esculentus (L.) Moench) 62%, 'Kuroda' 39% and 'Nantes' 50% carrots (Dauca carota L.), green beans (Phaseolus vulgaris L.) 41%, cucumber (Cucumis sativus L.) 43%, cabbage (Brassica oleracea (L.) var. capitata) 35%; and tomato (Lycopersicon esculentus Mill.) 53%. In Nigeria, yield losses of 40 to 50% were incurred from weeds in transplanted and irrigated onions (Deat, 1983). Shadbolt and Holm (1956) showed that tremendous yield losses can occur even with a minimum number of weeds allowed to compete with the crop. For instance, a 15% weed stand reduced carrot and onion (Allium cepa L.) yields by 39% and 48%, respectively; when competition occurred for 38 and 35 days. Thus, Klingman et al. (1975) recommended weed control programs that approached 100% in vegetables. However, with rising costs of production, effective and economical weed control strategies should be promoted.

Weeds exert tremendous pressure on humans. Akobundu and Okigbo (1984); and Deat (1983) reported farmers in tropical Africa were spending 40 to 50% of their crop production time controlling weeds. A pesticide analysis survey (Lerch and Zemp, 1983) revealed that herbicides occupied the largest market share at 42%, probably indicating the gravity of the weed problem among chemical weed control users. The intensity with which vegetables are grown would mean farmers spending much more time on weed control especially where production is seasonal (William, 1979).

Akobundu (1982) noted that weed control and fertilizers were among the highest cost items in crop production in tropical Africa where capital was limiting. Cousens (1986) indicated growers had realized that profit maximization was not synonymous with yield maximization; hence were adopting ways to reduce costs and optimizing profit. Ivens (1971) reported dramatic seed cotton yield increases (900 to 2100 kg/ha) in Kenya when a lighter 'Dutch' hoe was adopted for weed control instead of the traditional heavy one; and weeding operations were started earlier. He suggested that simple technological improvements like these be extended to other crops. Cover cropping probably is one such technology that might help deal with the weed problem.

Many researchers agree that weeds are most injurious to vegetables in the early stages of growth (Shadbolt and Holm, 1956; William and Warren, 1975; Zimdahl, 1980; Sajjapongse et al., 1983) while others (Holm, 1971; Moody, 1975; William and Chiang, 1976) suggested cropping systems that ensure timely weed control. William (1979) also suggested integrating into crop production systems feasible technologies like a lighter hoe for early weeding, mulching and cover cropping that would meet the economic aspirations of vegetable growers. Bleasdale (1959) had shown that a 38% reduction in the amount of weeds present prior to the first weeding resulted in a 42% saving in the amount of labour needed for later weeding in onions and red beets. In situations where delayed weed control is anticipated, practices that delay weed germination and emergence such as cover cropping or mulching need to be considered.

Cropping systems can influence types and intensities of weed infestation. Koch et al. (1983) rated soil cultivation and seed bed preparation very highly on influencing weed types and their densities in various cropping systems. Radosevich and Holt (1984) also noted that cultivation encouraged the germination of annual weeds.

Cover Croping and Weed Control

A cover crop can reduce or prevent erosion as well as control weeds. Akobundu (1980, 1982, and 1983); and Akobundu and Okigbo (1984) reported that intensive cropping resulting from increased human population in tropical Africa had led to a decline in soil fertility and an increase in the hard-to-kill weeds and weeding frequency. They proposed adopting crop and land management practices such as cover cropping and living mulches, that ensure sustained production without soil deterioration and weed increase. Numerous other researchers testify to the potential of cover crops in erosion and weed control (Jones, 1972; Lal et al., 1978; McGuire and Hannaway, 1984; Hofstetter, 1988; Miller et al., 1989; William, 1989). Some cover crop possibilities include grasses, legumes or their mixtures (Hofstetter, 1988; and Miller et al., 1989). Selection of cover crops depends on local conditions and purpose (Kell, 1942) but for weed control, rapidity of germination and growth are important considerations (Jones, 1972; Voelkner, 1979). Small grain cereals used as cover crops include: wheat (Triticum sativum L.), rye (Secale cereale L.), barley (Hordeum vulgare L.), oats (Avena sativa L.) and sorghum (Sorghum bicolour Moench) (Miller et al., 1989). Akobundu and Okigbo (1984) indicated that about 4 to 6 t/ha of cover material should be provided for effective erosion and weed control. McGuire and Hannaway (1984) recommended annual grasses (including small grains) for short term rotations in tree nurseries because they generated more dry matter in less time; and decomposed slowly; thus offering prolonged protection to the soil and crops. Rye and barley in California not only produced high dry matter (6t/ha), but also 40 to 50% higher yields of potatoes, cabbage and sugar beet compared to the no cover treatments (Mertz, 1918). Investigating the use of cover crops in vegetables, Maynard and Bellinda (1989), identified winter rye, annual ryegrass (Lolium multifolium L.) and oats for possible use in tomato and cauliflower (Brassica oleraceae L. var. botrytis) production.

Quin (1973) in Nigeria, found growing unstaked tomatoes on a grass mulch to be economically attractive over staking unmulched crop or plastic mulching. A delayed weed emergence observed under the grass mulch resulted in scanty weed growth that only needed hand-pulling. Putnam and DeFrank (1983) noted a 75% inhibition in early weed growth in residues of several spring-seeded cover crops. Klingman et al (1975) indicated that densely planted, fast growing small grain cover crops offered considerable competition to weeds.

Good cover management enhances crop growth. Live covers compete with the crop for essential resources (Wiles, 1986; Graham, 1987; O' Dell, 1989). Wiles (1986) grew Pak choi (Brassica rapa (L.) cv. chinensis) in a chemically suppressed perennial ryegrass (Lolium perenne L.) living mulch. Burrill et al. (1988) indicated growth suppression could be achieved through mowing and flailing. Chen et al. (1989) in Nigeria, successfully alley-cropped paitsai {Brassica rapa (L.) cv pekinensis} (4.63 t/ha) by cutting the leuçaena [Leucaena leucocephala (Lam.) de Wit] hedgerows to supply nitrogen and prevent shading. Glyphosate {N-(phosphonomethyl) glycine} and paraquat (1,1'-dimethyl-4,4'

-bipyridium ion) also have been used to suppress cover crops (Wilson, 1978; Putnam, 1988; Katz and Ilnicki, 1989; Maynard and Bellinda, 1989). Killing or suppressing growth of cover crops by natural methods, however, would eliminate the use of herbicides, thereby, reducing production costs. Freyman (1989) effectively suppressed weeds in raspberry inter-rows with a barley mat formed after the cover crop was winter-killed. Cold tolerance generally is in the order: rye > wheat > barley > oats (Klingman et al., (1975) although cultivars may differ individually. Nuttonson (1955 and 1957) reported seedlings of wheat and barley can withstand temperatures as low as - 6°C and - 9°C, respectively. Oats, with leaves 20 - 23cm long and covered with snow, can endure low temperatures of - 9°C (Coffman, 1961). Other factors enhancing cold injury resistance include: seedling hardening, deep crowns, soil texture and soil moisture (Coffman, 1961; Briggs, 1978). Seeding rates of 150kg/ha or higher should be used for cereal cover crops meant for weed control (McGuire and Hannaway, 1984). Overland (1966) reported increased physical and allelopathic inhibition of chickweed (*Stellaria media* L.) with increasing proportions of barley plants. The realization that cover crops control weeds both physically and allelopathically may probably improve the attractiveness of the technology.

Allelopathy and Weed Control

Allelopathy refers to the detrimental effects of higher plants of one species on the germination, growth or development of plants of another species (Putnam and Duke, 1974 and 1978; Putnam and DeFrank, 1979; Aldrich, 1984; Rice, 1974; Putnam, 1988) and its occurrence is widespread in nature (Borner, 1960; Guenzi et al., 1967; Barnes et al., 1986; Putnam and Weston, 1986).

Roles of allelopathy in agriculture have been discussed (Patrick and Koch, 1958; Guenzi and McCalla, 1962; Overland, 1966; Putnam and Duke, 1978; Rice, 1974). Tukey (1969) indicated that allelopathy, implicated in the poor performance of crops under monoculture, could have influenced the adoption of such practices as crop rotation, cover cropping, residue or stubble mulching and fertilizer application.

Exploitation of allelopathy for weed control has been proposed (Putnam, 1979, and 1988; Altieri and Doll, 1979; Walker and Buchanan, 1982; Radosevich and Holt, 1984; Váradi et al., 1987; Dias and Moreira, 1988). Advantages of allelopathy in weed control may include: reducing costs of production and environmental pollution; requiring less expensive registration than synthetic chemicals; and safeness to user (Hager, 1980; Walker and Buchanan, 1982; Duke, 1986). Daar (1986) suggested the development of benign weed management methods to alleviate problems of rising costs of production, environmental pollution, weed resistance and contamination of groundwater associated with synthetic chemicals.

The half-life of most natural allelochemical compounds in the environment is very short (Putnam and Weston, 1986). Guenzi et al. (1967), for instance, noted no toxic chemicals in wheat and oat residues after 8 weeks of exposure to field environmental conditions while Rice (1979) found that phenolics, involved in the allelopathic properties of some plants, decomposed in 12 weeks. Almeida (1985), studying the effects of some mulches, concluded that the allelopathic persistence, and thus weed control, was positively correlated with the amount of straw produced and its rate of decomposition.

Allelopathic substances are liberated from plants through volatilization, exudation, decomposition and leaching. Whittaker (1970) and Aldrich (1984) reported the release of most allelochemicals from plants or residues primarily by decomposition and leaching. Safety to the user is, therefore, assured.

Controversy exists over the use of allelopathy for weed suppression. Problems include resistance and weed shifts (Steinsiek et al., 1982; Shettel and Bulke, 1983; Radosevich and Holt, 1984), selective weed control (Wall, 1983), the need for large quantities of materials (Almeida, 1985) and interference with plant growth (Walker and Buchanan, 1982).

Attempts to exploit allelopathy for weed control have focused on searching for superior weed suppressing types from germplasm collections; and breeding these characters into crop cultivars. Utilizing allelopathic types as rotational, companion or cover crops; and identification of new herbicides or precursor compounds. Superior weed suppressing types have been reported in cucumber (Cucumis sativus L.) (Putnam and DeFrank, 1974; Lockerman and Putnam, 1979; Putnam, 1987), oats (Avena sativa L.) (Fay and Duke, 1977), sunflower (Helianthus annuus L.) (Leather, 1983), rye (Secale cereale L.) (Barnes et al., 1986), sorghum (Sorghum bicolour Moench) (Alsaadawi et al., 1986) and soybean (Glycine max (L.) Merrill) (Massantini et al., 1977). Lockerman and Putnam (1979), for instance, found that cucumber selection PI 169391 reduced the stand of barnyardgrass (Echinochloa crus-galli L.) about 80% and redroot pigweed (Amaranthus retroflexus L.) 60% compared to the non-allelopathic cucumber (Pioneer) and the no cucumber controls. Allelopathic rye and its residues utilized as rotational or companion cover crops provided up to 95% control of weed biomass when planted in fall, killed in the spring and; peas and snap beans planted in the residues (Barnes and Putnam, 1983). Residues of barley, wheat, oats and sorghum have also provided effective weed suppression (Putnam and DeFrank, 1983).

The synthesis of new herbicides or precursor compounds from allelopathic higher plants and microbes has been reported (Duke, 1986; Putnam, 1988).

Among the factors involved in the production and release of allelopathic substances, Putnam (1989) considered the environment in which plants are grown, stress, and type and age of plant tissue. Nutrient deficiencies of nitrogen, phosphorous and potassium, for example, enhanced the concentration of chlorogenic acids and scopoletin in a variety of plants whereas greenhouse-grown plants produced less allelopathic chemicals due to the absence of ultra-violet light that is involved in the production of these substances. Putnam (1988) reported that surface residues of immature cereal grains were more inhibitory to the emergence of numerous summer annual weeds when compared to mature cover crops probably because they decompose quicker to release inhibitors.

Bioassay

Bioassay refers to the quantitative estimation, in standardized conditions, of biologically active substances on living organisms (Abercrombie et al., 1967). Bioassays are needed in the study of allelopathy to determine whether a specific plant-plant interaction has a chemical basis and also to help isolate and characterize the compounds causing the interaction (Shilling and Yoshikawa, 1987). Putnam and Tang (1986) considered bioassays as an important tool in the proof of allelopathy, the process of which is similar to Koch's postulates in that it requires the isolation of the chemical substances and testing them against the species they previously affected to see if they cause similar effects. Tukey (1969) described bioassays as the only method of analysis sensitive enough to detect the small amounts of growth regulators that are normally present in biological materials.

Several extraction and bioassay methods for allelopathic studies have been listed (Putnam and DeFrank, 1983; Leather and Einhellig, 1986). Cold-water infusion, hot-water extraction, autoclaving and organic solvent extraction were the common extraction methods while seed germination and/or seedling growth and development were the notable bioassays. Radosevich and Holt (1984), however, recommended the stairstep technique for detecting inhibitory root exudates. Pots of test crops and those of allelopathic species are arranged in series in a staircase in this technique and a culture solution applied to the uppermost is allowed to filter through all pots carrying root leachates with it which inhibit the growth of the test crops. Putnam and Duke (1978) considered cold-water infusion as the most common extraction method while inhibition of seed germination and/or plant growth and development were the common methods of bioassay (Patrick et al., 1964; Leather and Einhellig, 1986). Altered seed germination was reported as a criterion for allelopathic activity in all 96 bioassay studies reviewed (Stowe, 1979).

Bioassay materials are diverse and include both crops and weed species. Dias and Moreira (1988) reported lettuce, cucumber, tomato and some *Brassica* spp. were common bioassay species in vegetables. Putnam and DeFrank (1983), in a study designed to evaluate the influence of residues of several cover crops on vegetable and weed densities, utilized cucumber, lettuce, peas (*Pisum sativa* L.), radish

(Raphanus sativus L.), snap beans and tomatoes as indicator plants. Lockerman and Putnam (1979) used barnyardgrass (Echinochloa crus-galli L.) and redroot pigweed (Amaranthus retroflexus L.) to assess the allelopathic potential of cucumber accession PI 169391. Proso millet (Panicum miliaceum L.) and white mustard {Brassica hirta (L.) Moench.} were used to evaluate the 526 accessions of cucumber for allelopathic potential (Putnam and Duke, 1974).

MATERIALS AND METHODS

Three experiments were conducted at Oregon State University (OSU) vegetable research farm, east of Corvallis and in the glasshouse and growth chamber facilities in the 1989/90 academic year as follows:

1. Winterkill, Ground Coverage and Biomass Yield Determination

Four small grain spring cereals: 'Micah' barley, 'Yecole Rojo' wheat, 'Cayuse' oats and common rye; commonly grown in Oregon were tested for winterkilling and dry matter or biomass on a Chehalis silt clay loam soil. The four treatments (grass cover type) were assigned to 6 m x 3 m plots using a randomized complete block design with four replicates.

Planting was on 29th October, 1989 by broadcasting seed evenly on the soil surface and shallowly incorporating with a hoe. A seeding rate one-and-half times the normal 84 kg/ha was used. The higher seeding rate was intended to create competition among the seedlings which would help pre-dispose them to winterkilling. Seedling emergence was completed over a two-week period from the date of planting. Rainfall provided all the moisture needed to grow the cereal covers.

A basal-dressing with 40kg N/ha; 67kg P_2O_5/ha and 45kg K_2O/ha was applied to all the grass plots on 20 November, 1989 and was followed three weeks later by a top-dressing with 20kg N/ha of ammonium sulphate. These higher fertilizer rates were intended to stimulate vegetative growth which might pre-dispose plants to winterkill.

All three weedings conducted - 10 November and 28 December, 1989, and 19 March, 1990 were by hand hoeing.

Observation on ground coverage by the different cereals was made visually while plant height was measured with a ruler at the expected time of winterkill and were completed on 17 March, 1990. On 18 March, 1990 a weed density assessment and collection of cereal and weed fresh weight samples were completed. Twenty polyvinylchloride (pvc) rings (Elmore et al., 1989), each 15 cm in diameter and covering $0.02m^2$, were randomly scattered in each plot. Weed presence contained within each ring were counted and recorded. Cereal and weed dry matter samples were collected from three random quadrants ($0.25m^2$) per plot and were weighed fresh and after drying. A tunnel dryer at 110^oC was used in drying the samples.

Mature cereals were mowed with a tractor on 20 May, 1990 to prepare the plots for vegetable growing. Bioassay crops of lettuce, tomato, cabbage and cucumber were direct seeded by hand in all plots on 14 July, 1990. Sampling for dry matter to assess whether allelochemicals affected growth of bioassay plants began on 17 August, 1990 and continued for three weeks.

2. Weed Suppression and Allelopathic potential of 'Micah' Barley

'Micah' barley was tested for weed control and allelopathic potential in a randomized complete block design conducted on a Chehalis silt clay loam soil at the OSU vegetable research farm. The four treatments: full cover, 30cm strip, 60cm strip and the no cover control; were randomly assigned to $30m^2$ plots in each of the four replicates.

On 30 October, 1989 'Micah' barley was sown in three of the four plots in each replicate. At a seeding rate of 126 kg/ha, seeds were hand broadcast evenly and shallowly incorporated into the soil by a hoe.

A pre-plant application of 40kg N/ha, 67kg P_2O_5/ha, and 45kg K_2O/ha was made on 20 November, 1989 and top-dressed with 20kg N/ha sulphate of ammonia three weeks later.

Three hand weedings to control winter weeds were conducted on 10 November and 28 December, 1989; and 19 March, 1990.

On 10 Apr., 1990 `Micah' barley (at booting) and the weedy control were killed by a 1% glyphosate [N-(phosphomethyl) glycine] solution. The dried cover was rolled down by a tractor-mounted roller four weeks afterwards while the control plots were scraped clean of weeds.

Bioassay crops included: tomato cv. 'Celebrity' from Harris Moran Seed Co.; and lettuce cv.'Buttercrunch', cucumber cv. 'Spacemaster' and 'Golden acre' cabbage all from Chas. H. Lily Company.

Tomato seedlings were raised in pots in the glasshouse. A soil mix was prepared consisting of 1 parts sand: 1 part soil: 1 part peat moss: 2 parts pumice to which were added 60g calcium nitrate, 77g sulfomagnesium, 48g triple superphosphate, 8g FTE and 122g lime. On 24 April, 1990; two tomato seeds per pot, were sown into 640 pots. Two weeks after emergence, seedlings were thinned to a single plant per pot. On 26 May, 1990 the four-weeks old seedlings were transplanted into permanent positions spaced 90 cm x 60 cm. in the field.

Cabbage, lettuce and cucumber were direct-seeded on 20 June, 1990. The seeding rates were 1.25, 1.5 and 3kg/ha for cabbage, lettuce and cucumber, respectively. Cabbage and lettuce were hand-planted into shallow grooves in a 15cm wide and 6m long band opened with a pick; while cucumbers were sown at 30cm intervals in the band.

Different rates of fertilizers were applied to each crop. Tomatoes were basal-dressed with 84kg N/ha, 112kg P_2O_5/ha and 112kg K_2O/ha one week after transplanting and top-dressed three weeks later with 45kg N/ha of sulphate of ammonia. Cucumbers received a banded basal-dressing of 45kg N/ha, 134kg P_2O_5/ha and 45kg K_2O/ha at the time of sowing and a sulphate of ammonia top-dressing of 45kg N/ha as the vines started to run. The amounts applied to lettuce included: a basal-dressing of 50kg N/ha, 120kg P_2O_5/ha and 50kg K_2O/ha and a top-dressing of 34kg N/ha. Cabbage was basal-dressed with 45kg N/ha, 112kg P_2O_5/ha and 50kg K_2O top-dressed twice (at 3 weeks after basal-dressing and yet again 3 weeks after the first one) with a total of 55kg N/ha sulphate of ammonia.

Weeds were counted, using 'pvc' rings 6 weeks after crop establishment in order to determine the level of weed control in the different treatments. Cucumber harvesting started on 15 August, lettuce on 19 August and tomatoes on 31 August, 1990. Multiple harvest was used for all crops and yield data were recorded.

3. Seed Germination Bioassays for Allelopathy Determination in the Grass Cover Crops

After observing positive weed control results in the field, a seed germination bioassay experiment was initiated in OSU's west greenhouses and growth chambers to verify allelochemical involvement.

Five cereal grass covers : 'Micah' barley, 'Bawers' barley, 'Cayuse' oats, 'Yecole Rojo' wheat and common rye; were sown in 15 cm diameter pots on 11 September, 1990. Fifteen pots, each growing three plants, were used on each cover crop. Plants were spaced 5 cm apart in a triangle. A 1% glyphosate solution was used to kill the grasses after growing for one-and-a-half months and having attained the following heights: wheat 54 cm., 'Micah' barley 64 cm, common rye 71 cm, 'Bawers' barley 87 cm and 'Cayuse' oats 94 cm.

A 60 g sample consisting of both roots and tops (stems, leaves and flowers) was collected from each group of plants and soaked overnight at room temperature in 1500 ml distilled water on 15 November, 1990. The cold-water extract was filtered with Whatman's No.1 filter paper and 500 ml of filtrate were collected in clean water bottles.

The undiluted filtrates were applied to bioassay crop seeds of lettuce, tomato, cabbage and cucumber in a germination test started on 16 November, 1990. The completely randomized block design experiment with six treatments (5 extract solutions and a distilled water control) and three replicates used 50 seeds of lettuce, cabbage, cucumber and tomato per 10 cm diameter petri dish each lined at the bottom with two Whatman No.1 filter papers. The filter papers and the seeds were moistened with 4 ml of the respective extracts. Distilled water (4 ml) instead, was applied to the control. Petri dishes were placed in the growth chamber where the day and night temperatures were maintained at $27^{o}/22^{o}C$ with 16 hours of day light and 8 hours of darkness, respectively.

Seed germination and radicle length were counted and meusured, respectively on day 4 and day 8. The experiment was terminated after 10 days. Plants were considered germinated if their radicle was 2 mm or more.

RESULTS

Winterkilling and Cover Crop Biomass or Yield

a. Winterkill

All four spring cereal cover crops ('Micah' barley, 'Yecole Rojo' wheat, 'Cayuse' oats and common rye) failed to winterkill during the Corvallis winter in 1989/90. Both the mean daily minimum observed (0.9°C) and normal (0.5°C) (average of several years) temperatures (Fig.1) exceeded - 6°C and - 9°C reported for winterkill (Nuttonson, 1955 and 1957; Coffman, 1961). Although plants exhibited signs of stress after the 25 cm deep freeze in February, most survived. Other factors such as snow cover probably enhanced survival of plants like oats with low tolerance to frost injury (Putnam, 1988).

b. Cover crop ground coverage, plant height, weed number and; grass and weed biomass

'Cayuse' oats differed significantly from all other cereal cover crops in dry matter (16.8t/ha), ground coverage (90%) and weed dry matter yield (0.18t/ha) although weed numbers were not statistically different (Table 1). 'Cayuse' oats was observed to tiller more than other cover crops.

Common weeds observed in order of occurrence included: common chickweed (Stellaria media L.), annual bluegrass (Poa annua L.), shepherdspurse (Capsella bursa-pastoris L.), wild carrot (Daucus carota L.), little bittercress (Cardamine oligosperma L.) and red deadnettle (Lamium purpureum L.).

'Micah' barley was tallest (40 cm) and significantly differed from 'Yecole Rojo' wheat (20.5 cm), 'Cayuse' oats (32.5 cm) and common rye (27.0 cm) at about the time of expected winterkill.

Weed Suppression with 'Micah' Barley Residues and vegetable Yields

a. Weed Control

'Micah' barley residues suppressed weeds in the all the mulched treatments during the early stages of crop growth (Table 2). Weed number reduction ranged from 79% in the full cover to 85% and 88% in the 30 cm and 60 cm strips, respectively compared to the control. Weed populations among the mulched treatments did not differ but all were significantly ($P = 0.01$) different from the no cover control with the greatest weed infestation (5.3 weeds/plot).

Annual bluegrass, mayweed (Anthemis cotula L.), common chickweed, and many summer weeds present in the the control plots were suppressed in the mulched treatments except common groundsel (Senecio vulgaris L.) and mayweed, both of which erratically grew through the mulch especially in the full cover treatment.

b. Yields of Tomato, Lettuce and Cucumber Grown in 'Micah' Barley Residues

Establishment problems encountered in the mulched treatments (30 cm and 60 cm strips, and full cover) would account for the declining trend in total yields (Table 3) although these did not differ statistically from the control. Tomato and cucumber marketable yields were also not different statistically. Delayed harvesting accounted for the lower marketable yields in cucumbers.

Bringing the mulch too close to the plant rows seemed to affect crop growth and yield. The 60 cm treatment (Table 3) yielded lowest [tomatoes (70.2 t/ha of red and green), lettuce (12.5 t/ha) and cucumbers (27.6 t/ha)] among the different treatments.

Bioassay Tests to Determine the Allelopathic Potential of 'Micah' Barley and other Spring Cereals.

a. Seed Germination Tests

Germination of the small-seeded vegetables (lettuce, cabbage and tomato) was reduced by all cereal extracts (Table 4) except 'Bawers' barley on lettuce and cabbage. Tomato seeds exhibited the greatest germination reduction, ranging between 93 to 100% compared to 62 to 78% for lettuce and 66 to 100% for cabbage. All extracts did not affect germination of the large-seeded cucumber although reductions were apparent.

b. Inhibition of Radicle Elongation

All extract-treated bioassay seeds exhibited reduced radicle length (Table 5) and differed significantly (P= 0.05) from the distilled water control. Inhibition was greatest (88 to 100%) in the small-seeded vegetables (lettuce, cabbage and tomato) compared to the large-seeded cucumber with a 71-81% range.

'Micah' barley inhibited radicle elongation as much as the allelopathic 'Bawers' barley in all seed types and both differed significantly from seeds germinated in distilled water (control).

Germinated extract treated seeds were discoloured at the root apical meristematic tissue and subsequent growth or elongation ceased.

DISCUSSION

Results on winter killing showed total failure of that strategy for suppressing the growth of cereal cover crops under the warm winters of Corvallis (Fig. 1). The technology will have to continue using either chemical or mechanical (slashing, mowing, flailing and flaming) methods of suppression. Success with winterkilling by other researchers has varied from moderate (Barnes et al., 1981; Putnam and DeFrank, 1979 and Putnam, 1984) to successful (Freyman, 1989) suggesting the strategy can work. Relevance of this technology to vegetable growers (especially small-scale producers) and its potential for resolving problems of rising costs of production, pollution and drudgery associated with some weed control methods requires further evaluation of winterkilling or other natural suppression methods.

In areas like Corvallis where temperatures occasionally fall below zero, success will depend on careful selection of cultivars (Kell, 1942; Voelkner, 1979; Klingman et al., 1975) and adopting management practices like higher rates of seeding (Barnes and Putnam, 1981; McGuire and Hannaway, 1984) and nitrogen fertilizers to pre-dispose plants to cold damage. Factors like cold hardening, age or size of the plant and deeply growing crowns implicated in enhancing plant survival during low temperatures (Coffman, 1961; Briggs, 1978 and Jones, 1983) besides snow cover and relatively warm winters, could probably be overcome through such stresses.

Seeding (126 kg/ha) and fertilizer (60 kg N/ha) rates used in this experiment were inadequate to induce winterkill.

Although 'Cayuse' oats outyielded all other cereals in dry matter and effectively covered the ground and controlled weeds (Table 1), it does not resist temperatures below zero without protection making it a risky choice for cover cropping. 'Micah' barley grew fast (40 cm) whereas rye produced greater dry matter (12.2 t/ha) and both can tolerate cold damage, and these attributes enhance their suitability for cover cropping. Barnes et al. (1986) and Miller et al. (1989) reported that rye and barley were among the popular cover crops in Michigan and California, respectively because they grew fast and produced adequate dry matter. Planting these two covers at higher densities and killing them earlier than May would probably provide the 4-6 t/ha of dry matter needed for effective weed control.

Better weed control reflected in low dry matter and greater cereal dry matter attained by 'Cayuse' oats (Table 1) could be explained by the high plant density (90% ground coverage) which shaded weeds and reduced photosynthesis. Sweet (1974) reported that if crops reduced incident light 50% or more, most weeds seldom become a problem while Moss and Hartwig (1980), Zimdahl (1980), Aldrich (1984), and Radosevich and Holt (1984) reported enhanced crop competitiveness against weeds at higher plant densities. The stand of 'Cayuse' oats was not only better but also the crop was observed to tiller more profusely, thus compensating for the lower rates of seeding.

Excessive quantities of dry matter in rye (12.2 t/ha) and oats (16.8 t/ha) were difficult to manage. A seed bed 30 cm wide had to be made to facilitate seed germination and seedling establishment. Barnes (1981), Akobundu and Okigbo (1984), and McGuire and Hannaway (1984) reported that only 4-6 t/ha of dry matter was needed as surface residues to effectively control weeds and soil erosion. Leaving covers grow to maturity in order for them to accumulate more dry matter is unnecessary.

Sowing barley or rye at higher rates to improve ground coverage and growing them for three to four months before suppression would yield the 4-6 t/ha necessary for weed control. Excessive residues not only create a different environment from that needed for seed germination and establishment due to their effects on moisture, light and temperature (Aldrich, 1984 and Barnes et al., 1986); but they also host pests (Dias and Moreira, 1988), and interfere with field operations, growth of succeeding crops (through production of phytotoxic compounds) and availability of nitrogen (Elliot and Cheng, 1987). Cutworms (Agrotis ipsilon Hufn.), slugs (Agriolimax agrestis L.) and mice (Mus spp.) were some of the major pests observed in the field experiments where they caused damage to seedlings and mature crops.

'Micah' barley mulch (9 t/ha) suppressed weed emergence and growth for six weeks after planting lettuce and cucumber and after transplanting tomatoes (Table 2). The scanty weed growth observed in the mulched treatments could either be due to the residues that prevented light from reaching the soil to effect weed seed germination (Aldrich, 1984; Radosevich and Holt, 1984) or the creation of an inhibition zone through the release of allelopathic substances in the top 5-7.5 cm of the soil where most small-seeded weed seeds germinate.

Although weed numbers (Table 2) is a valid measure of control efficacy, using it as a criterion for weed control requires good judgment of the weed situation and types because of the wide range of density-yield responses. Aldrich (1984) reported one kochia (Kochia scoparia L.) per row of sugar beet reduced yield 26%. Common groundsel, the most prevalent weed in this experiment, however, was observed to be less competitive.

Weed control results with 'Micah' barley mulch (Table 2) indicate that herbicide usage can be reduced through cover cropping. Other than the glyphosate that was used to desiccate 'Micah' barley at the beginning of the season, no more herbicide was applied. Barnes and Putnam (1983); and Putnam and DeFrank (1979) reported similar results with snap beans and peas grown in allelopathic rye residues. Growers interested in reducing costs of production might want to consider adopting cover cropping to complement chemical weed control.

Although the trend shows declining yields, marketable crop in tomato (Table 3) was high in all treaments and compares well with Wilson (1979) who reported marketable yields of 39-46 t/ha in both mulched and unmulched treatments. The control had most weeds (Table 2). Lack of difference in yield among treatments however suggests weeds did not interfere with crop growth. In fact most of them were observed growing between rows and not within.

The high yields (Table 3) also suggest the suitability of cover cropping to the vegetable growing system of Corvallis where winters interrupt continuous production. Land sown to a cover crop in the fall produced adequate residues (Table 1) by spring for use in the next season's vegetable crop.

A similar system for smallholder farmers of the tropics, however, requires careful planning with respect to rotation, cover selection and sowing times. Smallholdings common among small-scale producers may not allow long rotations while desiccation of cover crops with herbicides may not be possible due to lack of knowledge, cost or chemical inavailability.

Grasses that can be undersown in maturing crops, grow quickly and succumb to natural killing through heat and drought in the dry season should be considered for relay cropping. Intercropping of both vegetables and field crops common in Malawi could use allelopathic or smother crops like pumpkin [Cucurbita pepo (L.) var. pepo] or squash [Cucurbita pepo (L.) var melopepo] as companion crops for weed control. Planting of these must be timed to avoid interference with the main crops. Several non-crop plants like velvet beans (Stizolobium deerengiunum L.) can also be managed for weed control in short term rotations.

Covers hold promise for the multiple enterprises including rain-fed vegetable growing, common among small growers. Saving in labour, improvement in soil fertility and organic matter, conservation of soil moisture and control of erosion and weeds are some of the benefits that would accrue to growers adopting this technology since only scanty weed growth that only needed hand-weeding was observed in all the mulched treatments.

The scanty weed growth observed in the 30 and 60 cm bare strips of 'Micah' barley mulched treatments (Table 2) also suggests that suppression was both physical and allelopathic. Bioassay results (Tables 4 and 5) confirm that 'Micah' barley residues contained chemical inhibitors which reduced or inhibited either seed germination, radicle length or both processes in the test species - tomato, lettuce, cabbage and cucumber. Germination and radicle elongation of small-seeded bioassay crops (tomato, lettuce and cabbage) were inhibited most compared to the large-seeded cucumber. Putnam (1987) reported similar results with residues of several cover crops including barley.

Inhibition of radicle elongation in all seed types by the extracts (Table 5) suggests that it is a more sensitive measure of allelochemical activity than seed germination (Table 4). Root tips of most bioassay seeds germinated in extracts were observed to turn brown while seeds that failed to germinate turned black. These symptoms of injury were consistent with previous reports (Barnes et al., 1986 and Aldrich, 1984). Growth of root hairs observed in the control was suppressed in all extract germinated seeds. Allelochemicals in the extracts seem to inhibit cell division and elongation in the root meristematic region among other biochemical processes. The observation is consistent with results of Rice (1974) and Aldrich (1984) who reported cell division and elongation among processes that allelochemicals can affect.

Extracts from 'Bawers' barley affected radicle elongation more than seed germination (Tables 5 and 4) in all seed types. Long periods of exposure to the concentrated extracts explains why it affected germination of tomato which required the longest to germinate among the bioassay crops. Elliot and Cheng (1987) reported enhanced allelopathic inhibition when a seedling or plant was in intimate contact with decomposition chemicals or when these were transferred directly from residues to the plant. Evanari (1949) reported irreversible seed damage after 7 days exposure to allelochemical. Variability among plants in types of allelochemicals contained and the specificity in the biochemical processes they affect is demonstrated by these results. Inhibitors in 'Bawers' barley extract seem to prevent cell elongation. The high concentration of extracts used in germinating seeds could be the reason why all inhibited radicle elongation. Results confirm those of Borner (1960); Patrick et al. (1964), Guenzi and McCalla (1966), Shettel and Balke, (1983), and Aldrich (1984) who reported that the activity of allelochemicals is concentration dependent and that their release occurs early in the decomposition process. Results also agree with those of Putnam and Duke (1978) regarding the effectiveness of cold-water for inhibitor extraction.

SUMMARY

Three experiments whose objectives were to investigate weed suppression by cereal cover crops desiccated by winter freeze and to assess their allelopathic potential were conducted at the Vegetable Research Farm and in the greenhouse and growth chamber facilities at OSU in 1989/90. Desiccation by winter freeze had failed under the relatively warm winters of Corvallis in 1989/90. Complementary usage of cover crops and herbicides for weed control is suggested.

Residues of herbicide killed 'Micah' barley suppressed weed emergence and growth for up to six weeks in tomatoes, lettuce and cucumber. Besides physical weed control, allelochemicals were involved. Greenhouse and growth chamber bioassay tests confirmed the presence of seed germination inhibitors in residues of 'Micah' barley and other cereal covers.

No differences in yield among treatments were observed for each crop when weeds were controlled six weeks after planting.

Improved weed control and increased organic matter are some of the benefits shown by these results. Small-scale growers, like those of Malawi, characterized by small land holdings and multiple enterprises that lead to labour conflicts might experience increased productivity through cover cropping since it suppresses early season weed growth; thus allowing growers to weed their priority crops. Benefits are likely to increase if ways to harness natural killing or suppression of cover crops and mechanize operations can be found.

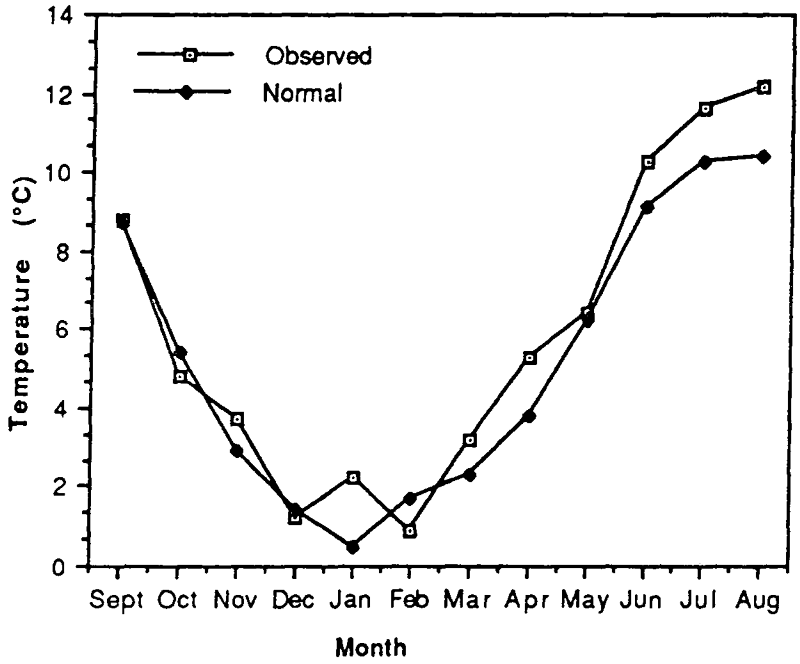

Fig. 1 Mean daily minimum temperature (°C) for Corvallis 1989/90

Table 1. Grass and weed biomass; and other important cover crop parameters for weed control: 1989/90.

Cover crop	Ground coverage (%)	Plant height (cm)	Weed numbers	Biomass (Dry wt) grass	weed
				----(t/ha)----	
Yecole Rojo wheat	62.5d	20.5d	1.5	8.9c	0.69c*
Micah barley	75.0c	40.0a	2.1	9.0c	0.72c
Cayuse oats	90.0a	32.5b	1.9	16.8a	0.18a
Common rye	82.5b	27.0c	2.0	12.2b	0.58b

* Figures in a column followed by the same letter are not statistically different (P = 0.05) by Duncan's Multiple Range test.

Table 2. Weed densities in `Micah' barley mulched and unmulched treatments six weeks after planting bioassay vegetables.

Treatment	Number of weeds/plot ($30m^2$)
No cover (disturbed)	5.3a*
30cm strip (disturbed)	0.8b
60cm strip (disturbed)	0.6b
Full cover (undisturbed)	1.1b

* Figures followed by the same letter are not statistically different (P =0.01) according to Duncan's Multiple Range test.

Table 3. Total and marketable yield (t/ha) of tomato, lettuce and cucumber grown in a 'Micah' barley mulch: 1990.

Treatment	Yield		
	Tomato*	Lettuce	Cucumber
	------------(t/ha)------------		
No cover (control)	77.5 (45)	16.3	46.3 (12)+
30cm strip	86.3 (44)	13.0	36.9 (9)
60cm strip	70.2 (47)	12.5	27.6 (11)
Full Cover	73.9 (47)	12.6	40.9 (11)
	NS NS	NS	NS NS

* Transplanted.

\+ Figures in parenthesis represent marketable yield.

Table 4. Effect of cold-water extracts from greenhouse-grown cover crops on seed germination of bioassay crops: 1990.

	Seed germination			
Treatment	Tomato	Lettuce	Cabbage	Cucumber
	----------(percent)-------------			
Distilled water (control)	75a	87a	93a	85a*
Yecole Rojo wheat	3b	33b	32b	40a
Micah barley	2b	19b	11b	28a
Bawers barley	2b	48a	37a	48a
Cayuse oats	5b	30b	23b	73a
Common rye	0	21b	0	39a

* Figures in a column followed by the same letter are not significantly different (P = 0.05) by Duncan's Multiple Range test.

Table 5. Inhibition of radicle elongation by cold-water extracts from greehouse-grown cover crops.

Treatment	Radicle length			
	Tomato	Lettuce	Cabbage	Cucumber
	----------------(mm)----------------			
Distilled water (control)	10.6a	13.1a	17.0a	9.1a*
Yecole Rojo wheat	1.3b	0.9b	0.3b	2.4b
Micah barley	0.5b	0.8b	0.03b	1.7b
Bawers barley	1.2b	0.8b	0.8b	2.2b
Cayuse oats	1.3b	0.8b	0	2.1b
Common rye	0	0.4b	0	2.6b

* Figures in a column followed by the same letter are not statistically different (P = 0.05) by Duncan's Multiple Range test.

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