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Agronomy of strip intercropping broccoli with alyssum for biological control of aphids

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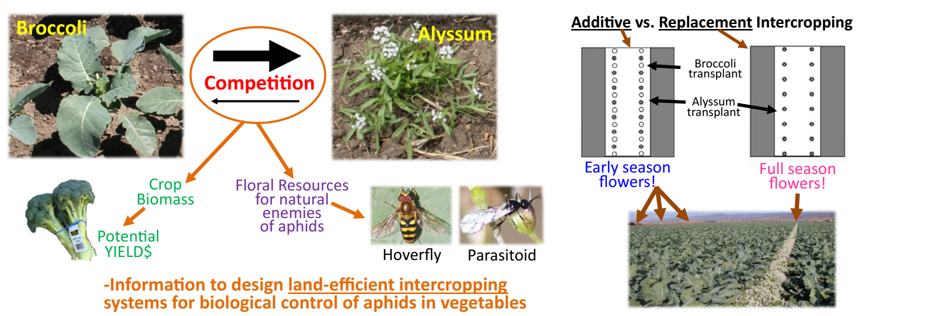
HIGHLIGHTS

- Broccoli was much more competitive than alyssum and produced more shoot dry matter.
- Alyssum flower counts increased linearly with alyssum plant size.
- Alyssum transplants produced more flowers per transplant on beds without broccoli.
- Bed sections with only alyssum are recommended for all-season floral resources.
- Additive intercropping is recommended to efficiently provide early-season flowers.

GRAPHICAL ABSTRACT



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ABSTRACT

Organic broccoli growers in California typically control aphids by intercropping broccoli with strips of alyssum (*Lobularia maritima* (L.) Desv.) which attracts hoverflies (Diptera: Syrphidae) that are important predators of aphids. A three year study with transplanted organic broccoli in Salinas, California evaluated agronomic aspects of broccoli monoculture (B100) and broccoli-alyssum strip intercropping on beds in replacement intercropping treatments where alyssum transplants replaced 4 or 8% of the broccoli transplants, and an additive intercropping treatment (B100 + A100) where alyssum transplants were interspersed between broccoli without displacing it. The replacement patterns included alyssum planted on both lines of a bed (A100), beds with 50% broccoli and 50% alyssum transplants in different lines (B50A50D), and beds with 50% broccoli and 50% alyssum alternating in the same lines (B50A50S). To evaluate competition, shoot dry matter (DM) of alyssum and broccoli was measured at 36–43 days (harvest 1) and 59–66 days (harvest 2) after transplanting, and alyssum flowering was assessed at both harvests. The treatments performed consistently across years. The number of flowering alyssum shoots was highly correlated with alyssum DM. Per alyssum transplant, alyssum DM was highest in A100 and B50A50D at harvest 1, and by harvest 2 (3–7 days before broccoli maturity) was in order of A100 > B50A50D > B50A50S = B100 + A100. Broccoli was much more competitive than alyssum and by harvest 2 produced larger broccoli shoots per transplant in B50A50S (122 g) and B50S50D (96 g) than the more ideally sized shoots (73 g) in B100 and B100 + A100. The A100 pattern may be the most efficient replacement intercropping strategy to provide hoverflies and parasitoids with floral resources through the whole season, however, additive intercropping may also be useful to augment floral resources early in the season without displacing broccoli. These results can help growers reduce the cost of alyssum intercropping in high-density broccoli systems (>100,000 transplants per ha). The practical management implications and future research needs to further improve the efficiency of these systems are discussed.

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1. Introduction

After lettuce (*Lactuca sativa* L.), broccoli (*Brassica oleracea* L. var. *italica* Plenck) is the most economically important vegetable grown in the Salinas Valley (Monterey County) on the central coast of California, with an annual production value of more than U.S. $400 million harvested from 26,538 ha (Monterey County Agricultural Commissioner, 2013). While broccoli and other crucifer vegetables are widely known for their anticancer health benefits to humans (Verhoeven et al., 1997), growing broccoli in rotation with lettuce and strawberry (*Fragaria* × *ananassa* Duch.) may also improve soil health by suppressing soil-borne diseases (Hao et al., 2003; Subbarao et al., 2007). With the dramatic growth of the organic industry in the Salinas Valley from a production value of approximately $11 million in 1994 to $274 million in 2014 (Monterey County Agricultural Commissioners, 1999, 2014), there has been increased research on intercropping vegetables with insectary plants to enhance biological control of aphids (Brennan, 2013; Chaney, 1998; Gillespie et al., 2011; Smith and Chaney, 2007). However, these previous studies were all focused on lettuce. The only known intercropping research to control aphids in other vegetables in Salinas Valley was with living mulch cover crops in broccoli that reduced aphid infestations (Costello, 1994; Costello and Altieri, 1995); however, this practice has not been adopted here.

Insectary plants attract beneficial insects into fields and provide floral resources (pollen and nectar) that these insects need to survive and reproduce, and which contributes to biological control of pest insects (Parolin et al., 2012). This is a form of conservation biological control that can make highly disturbed agroecosystems more hospitable environments for natural enemies of agricultural pests (Jonsson et al., 2008; Landis et al., 2000). Alyssum (*Lobularia maritima* (L.) Desv.) is a frequently studied plant for biological control in many agroecosystems (Araj and Wratten, 2015; Brennan, 2013; Fiedler et al., 2008; Gontijo et al., 2013) and is a popular insectary plant in California because it flowers quickly, attracts several beneficial insect species and few pests, and is not overly aggressive or likely to become a weed (Chaney, 1998). Hoverflies (Diptera: Syrphidae) are a common beneficial insect in California organic vegetable production (Bugg et al., 2008) and alyssum pollen is an important food for adult hoverflies in these systems (Hogg et al., 2011).

The cabbage aphid (*Brevicoryne brassicae* L.) is the primary insect pest of broccoli in Monterey County and its most common natural enemies here are a parasitoid wasp (*Diaeretiella rapae*, McIntosh) and aphidophagous hoverflies (Nieto et al., 2006). The most common approach that growers here use to control cabbage aphid in organic broccoli is to interplant broccoli with alyssum. Perennial hedgerows on field edges are also used on some organic farms in California to provide floral resources for a diversity of natural enemies of aphids and other pest insects (Brennan, 2015; Earnshaw, 2004; Gareau et al., 2013; Morandin et al., 2011). To increase the adoption and efficiency of vegetable-insectary intercropping for biological control of pest insects, farmers need basic agronomic information on growth characteristics of insectary plants that will maximize their flower production per unit of land area. This is especially true in regions like the Salinas Valley where high agricultural land rents ($3700–7400 per ha) limit the land area that farmers can allocate to insectary plants. Historically, ‘replacement intercropping’, whereby vegetable plants were replaced (i.e., displaced) by insectary plants in strips or scattered through the field, was the most common approach used; alyssum intercrops typically replace 5% of the broccoli in organic production systems (Tourte et al., 2004). However, research with lettuce found that additive intercropping, whereby insectary plants are inserted between lettuce plants without displacing them, was a far more land-efficient intercropping approach than replacement intercropping (Brennan, 2013) and effective for aphid control (Brennan, 2014).

A three year study was conducted in transplanted organic broccoli that was strip intercropped with ‘replacement’ and ‘additive’ arrangements of alyssum from July to September. The objectives were 1) to determine the relationship between alyssum shoot biomass and flower production in broccoli, 2) to evaluate competition between the intercropped plants by measuring their shoot biomass, and 3) to identify the most land-efficient intercropping strategies to maximize alyssum flower production in high density broccoli production (i.e., >100,000 plants per ha).

2. Methods

2.1. Site description, field preparation, and soil amendments

The experiment occurred at the USDA-ARS organic research farm in Salinas, CA (lat. 36.622658, long. −121.549172, elevation 37 m), where the soil is a Chualar loamy sand (fine-loamy, mixed, superactive, thermic Typic Argixerol). The site has been certified organic since 1999, and inputs described were allowable under the USDA National Organic Program. The experiment occurred in a 48 by 15 m area on the east side of a 0.9 ha field that has been in a long-term, commercial-scale trial (Brennan and Boyd, 2012b) with an annual rotation of romaine lettuce (May to June), broccoli (July to October), and winter cover crops (October to March), since 2003. Management details of the cover crops and lettuce that preceded the broccoli each year are in Brennan (2013). During the 23–33 d period between the harvest of the lettuce and transplanting of broccoli, the following field preparation occurred: (1) the lettuce residue was incorporated into the soil with standard tillage equipment as needed to promote decomposition, and peaked beds (101.6 cm wide) were formed, (2) urban yard-waste compost (C:N ≈ 22) was broadcast at approximately 7.6 Mg per ha (oven-dry basis) onto the beds and incorporated with a rolling cultivator, (3) pelleted organic fertilizer of chicken manure and feather meal (8N-1P-1K) was injected into the beds at rates of 133, 125, and 141 kg N per ha with a fertilizer applicator in two bands 27 cm apart, and approximately 15 cm deep on 13 July, 26 June, and 2 July, for 2007, 2008 and 2009, respectively, and (4) the peaked beds were then shaped with a bed harrow to produce a flat planting area on the bed top that was approximately 50 cm wide and 15 cm above the furrow bottoms (Fig. 1). These field preparation procedures are typical for commercial-scale, organic broccoli production in this region.

2.2. Experimental design and intercropping arrangement

The experimental design was a randomized complete block with 4 blocks of five treatments of interest including broccoli monoculture (B100) and four strip intercropping treatments. Each block was 10.2 m wide (10 beds) and 15 m long. The experimental unit for each treatment was a single bed with two transplant rows. In addition to the five treatments described here, each block contained five additional broccoli-alyssum intercropping treatments that were not of interest and were excluded from the analysis. As in similar research with lettuce (Brennan, 2013), the furrow between adjacent beds was considered an adequate buffer area to prevent competition between adjacent treatments. This assumption that plants on adjacent beds did not affect each other is reasonable up to the first harvest where the leaves from adjacent beds were not overlapping. Moreover, if there was any competition between plants on adjacent beds thereafter, this would not likely