Nick Tsichlis
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Fortifying a Perimeter Trap Cropping System Through the Addition of a Push-Pull Mechanism

Introduction and Background

Widely grown throughout the United States and with harvests valued at over $500 million annually, sweet bell peppers (*Capsicum annuum* L.) are an important source of revenue for farmers. Because of their high value and number of days to maturity once the fruit sets, farmers often preventatively spray insecticides on this crop. In Brazil, for instance, sweet peppers often have the highest pesticide ranking index of any commercially available food (Souza et al., 2019). Conventional treatments in the US often involve two annual organophosphate and bi-weekly pyrethroid applications. This system, which necessitates five to ten yearly insecticide applications per crop, is currently the dominant production method for peppers and is responsible for several consequences including increased monetary costs, the elimination of natural enemies, the buildup of pesticide residues in the soil, and negative impacts on human health (Chapman et al., 2009).

A common pest of peppers in the eastern United States is the Pepper Maggot (*Zonosemata electa*). While bell peppers are the crop that is the most affected, studies have shown that the insect has exhibited a preference for cherry peppers (T. Jude Boucher et al., 2003). The pepper maggot is an impactful pest in the eastern US, has erratic distribution, and there is limited literature on the biology of the species. Classified as a member of the Tephritidae family, *Zonosemata electa* is a univoltine species whose pupae overwinter in the soil and emerge in mid-summer, locating solanaceous plants for mating and oviposition of eggs (Judd et al., 1991). Hardwood tree canopies at field edges harbor the pepper maggot adult populations and a daily migration occurs to the affected crop (Boucher et al., 2001). Traditionally, this pest has been managed through a mixture of broad-spectrum insecticides which are applied periodically to pepper crops. Phenological studies of the pepper maggot have led to the creation of specialized protocols that call for four timed, weekly insecticide applications coinciding with its emergence from the soil in late June. These methods have produced mixed results, likely due to mistimed sprays (Judd et al., 1991). The populations can become endemic when routine cover sprays are discontinued in favor of integrated pest management (IPM) or organic farming methods, and this can result in widespread crop loss (T. Jude Boucher et al., 2003). New, efficient biological control methods will be necessary to control populations of the pepper maggot in the future, and trap cropping systems may be effective in doing so.

There has recently been a surge of research on trap cropping as a potentially effective tool for insect pest control in organic and IPM farming systems. The negative effects of broad-spectrum pesticides on human health and the environment have become clear, and farmers are searching for other effective insect control methods (Shelton & Badenes-Perez, 2006). Trap cropping, which involves growing adjacent plant stands to crops which are more attractive to the insect pests either as a food source or for reproduction, have been effective in multiple agricultural scenarios. The trap crop plant can be the same species as the target crop or it can be unrelated, depending on the situation and the spatial and temporal arrangement of the plantings. Often it is a preferred cultivar or planted at a favored growth stage to increase attractiveness to the target pest (Cook et al., 2007). Another feature of conventional trap cropping systems is the "trap" component; often once the pests are concentrated in that area the trap crop is sprayed with insecticides, eliminating nearly the entire pest population (Shelton & Badenes-Perez, 2006). However, with many farms embracing reduced spraying regimens, modifications to the system have gained notoriety. Perimeter trap cropping, where the edges of the crop succession are manipulated and the selected trap crop surrounds the valued crop, has been an effective evolution. These systems have had significant deterrent effects on large insects such as beetles, butterflies, moths, and flies, which migrate from the field margins and locate hosts for oviposition using visual cues. The pepper maggot, a tephritid fly, possesses such sensory abilities so it is not a surprise that perimeter trap crop arrangements have been beneficial in intercepting them as they migrate to the field and in containing them (Potting et al., 2005).

Figure 1: The author harvesting peppers from within a perimeter trap crop system, Appleton Farms, Ipswich, MA, 2019.

Trap cropping can also be infused with other non-conventional approaches to decrease pest pressure to target crops. By including aspects of conservation biological control, which seeks to increase the effectiveness of natural enemies by positively influencing their survival rates and fecundity through physical manipulation of the system, it is possible to not only attract pests but also to attract and maintain populations of insects which prey upon them (Landis et al., 2000). The ubiquity of insecticide applications has precluded the adoption of most biological control methods in many agricultural systems, but certain biologically enhanced trap crop strategies have been proven effective and have recently gained popularity. The push-pull trap cropping system is one such example, where the population sizes and distributions of both pests and natural enemies in the field are manipulated through "behavior-modifying stimuli". Pests are "pulled" towards the trap crop and at the same time are "pushed" away from the target crop by an intercrop that can distort visual cues, produce deterrent semiochemicals, and harbor populations of natural enemies (Cook et al., 2007). While each strategy by itself does not result in the equivalent decline in pest pressure relative to chemical insecticide applications, this result may be achieved by the aggregate effect of multiple biological control methods employed simultaneously. Through a mixture of visual and chemical signals, push-pull systems can protect the valued crops by rendering them unattractive or unavailable to pests, and are an effective tool in systems that have reduced or eliminated conventional pest control inputs (Cook et al., 2007).

Figure 2: The farm crew at Appleton Farms in Ipswich, MA planting their bell pepper crop and perimeter cherry pepper trap crop, 2019.

There is ample evidence indicating that bolstering trap crop designs with push-pull mechanisms can result in higher crop yields, yet studies to this effect are rare in the literature. It has been shown that the cherry pepper perimeter trap cropping system is successful in creating a barrier that limits pepper maggot oviposition on interior bell peppers and has the potential to drastically reduce annual pesticide applications on pepper crops (Boucher et al., 2003). An IPM-focused perimeter trap cropping system that features rows of cherry peppers and an insecticide regimen has been shown to be effective in reducing oviposition by pepper maggot females. This system has successfully lowered annual crop losses for farmers (Boucher et al., 2003). However, anecdotal experience from utilizing this system on a New England farm produced inconsistent results (personal observation). While the border of cherry peppers acted as an effective trap crop and "pulled" a population of pepper maggot to that area, a large percentage of females still achieved successful oviposition on bell peppers in the interior block, resulting in significant crop damage. Although data was not collected, the author's and other's observations were that pepper maggot infestations were seemingly equally high in the bell pepper plants located one and two rows within the system as they were in the perimeter of cherry peppers. Secondary pests such as aphids were also prevalent throughout the crop. While it has been demonstrated that trap crops are effective in attracting larger insects such as tephritid flies, small arthropod herbivores such as aphids, thrips, mites, and whiteflies are less likely to respond to this type of behavioral manipulation (Potting et al., 2005). The perimeter trap crop represented an improvement from nothing, but it could be argued that it would be more effective in conjunction with other control measures.

Hypothesis

To optimize this pepper growing system and potentially eliminate all chemical and microbial insecticide inputs, additional experimentation with an agroecological focus is required. It is hypothesized that this system would be strengthened by including an intercrop within the bell pepper block that would attract natural enemies of the pepper maggot and potentially disrupt oviposition through other biological means. Similarly to the push-pull system in Africa that controls for multiple pests through increased chemical and species diversity (Khan et al., 2000) , the pepper maggot trap crop paradigm could be optimized with stronger natural defenses, potentially reducing the need for pesticide applications.

Rationale

Peer-reviewed literature suggests that the addition of aromatic plants, specifically basil (*Ocimum basilicum* L.), may reduce pepper maggot infestations through multiple means while simultaneously deterring secondary pests and strengthening the resilience of the system. Aromatic plants, defined by their essential oils and other volatile compounds, exhibit a multitude of positive and negative effects on both pests and natural enemies through their production of allelochemicals. These chemicals, which are the evolutionary product of both competitive and mutualistic interactions between plants and insects, can affect their communication in negative ways by acting as repellants, deterrents, antifeedants to adults, and can harm reproduction by deterring oviposition of pests or inhibiting the digestion of plant material by larvae.   They can also have a positive effect on predator populations by attracting them through olfactory cues and providing a food source and habitat refuge (Regnault-Roger, 1997). The benefits of intercropping with aromatic plants such as basil amongst target crops have been demonstrated in a wide range of settings, highlighting their functions as pest repellants and as attractants of generalist predators such as the green lacewing (Batista et al., 2017). Many natural enemies, which are active early in the morning and in the evening, are reliant on olfactory cues, and basil contains a high percentage of essential oils concentrated in trichomes on the leaf surface. This helps explain why the green lacewing was highly attracted to *O. basilicum* in the absence of other food sources in the Batista study. In fact, not only did the basil intercrop result in increased lacewing populations, but it's larvae were also sustained by the flower resources, indicating the potential of establishing generations of biological control in the system (Batista et al., 2017).

Figure 3: A bell pepper harvest from a perimeter trap crop system at Appleton Farms in Ipswich, MA, 2019.

The essential oils of aromatic plant species have been shown to have a positive effect on yields in many intercropping systems through a reduction of herbivory by pests (Yarou et al., 2018). Strip intercropping systems featuring *O. basilicum* plants have specifically been shown to significantly reduce aphid pest populations over a multi-year period (Basedow et al., 2006). Aside from the negative effects of the pepper maggot, herbivory by aphids was the largest observed source of damage to the pepper crops on a farm in Massachusetts in 2019. Moreover, the oviposition-deterring effects of this intercrop have been demonstrated in a multitude of studies on a wide range of pests including multiple lepidoptera species, and the essential oils of *O. basilicum* have exhibited repellent and oviposition-preventative properties on insect pests in the families Dryophthoridae, Curcuilionidae, Bostrichidae, Tenebrionidae, and Bruchidae (Yarou et al., 2018).

While increasing plant diversity in systems cannot be assumed to increase biological control (Andow, 1991), it has been demonstrated that intercropping *O. basilicum* and other aromatic plants in orchard systems reduces herbivore abundance and species richness relative to natural grasses or clean tillage (Beizhou et al., 2011) while simultaneously increasing those metrics for natural predator species, thus shifting the arthropod community structure dynamics and resulting in a predator-dominated trophic structure (Song et al., 2012). The observed reduction in herbivore populations can be attributed to the preventative effect of the volatile oils produced by *O. basilicum* on the ability of the pests to locate, feed, and reproduce on the crops. The increase in the ratio of natural enemies relative to herbivores is likely the result of the increase in food sources and suitable habitat provided by the intercrop (B. Song et al., 2012). Studies have shown that adult predators and parasitoids will utilize pollen and nectar as alternative food sources in the agroecosystems, so aromatic intercrops likely provide ecosystem functions that support natural enemies (Landis et al., 2000).

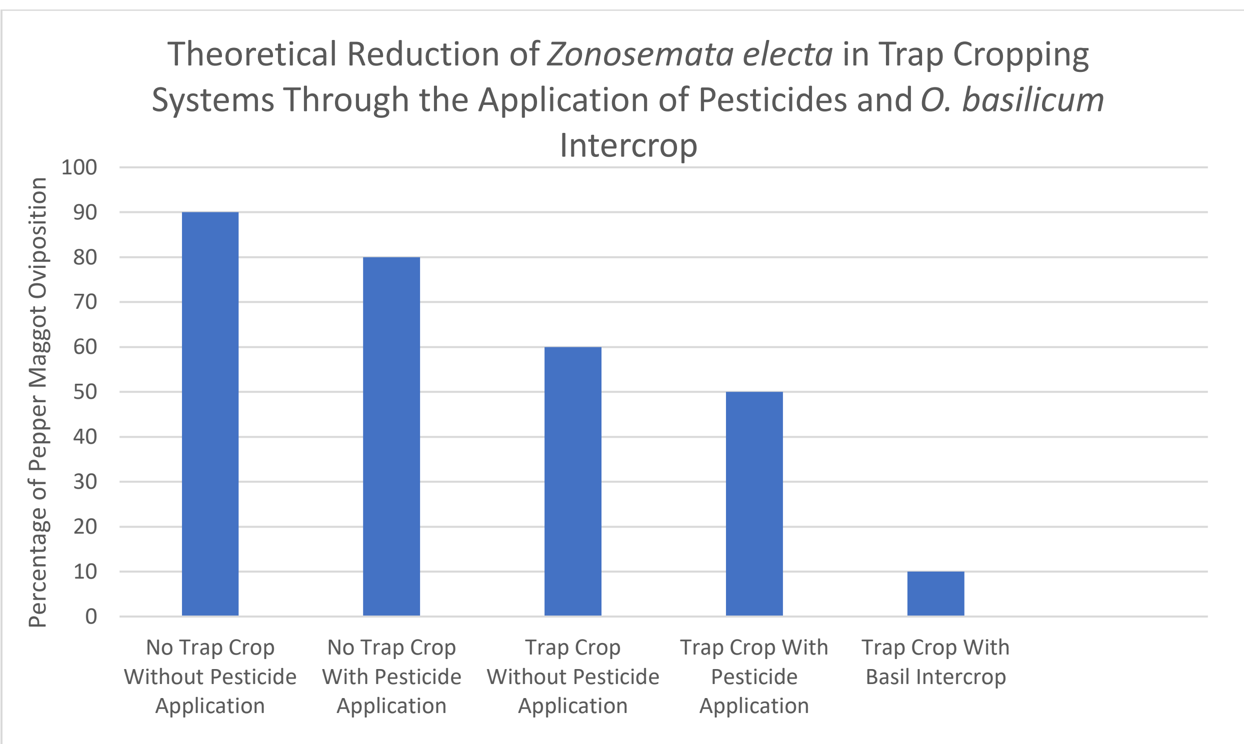
There are several explanations as to why *O. basilicum* is responsible for the shift from arthropod community structure to one that is predator-dominated: the repellant properties from the aromatic oils prevent certain herbivores from feeding, those airborne oils obscure the scent of the target host plants and thus reduce oviposition success in certain species, the chemical compounds within the plant are toxic to certain herbivores whereas ingestion results in malnutrition and death, and the increased groundcover provides habitat, protection, and alternate food sources to generalist predators and parasitoids (Song et al., 2010). The observed height of predator abundance was during the flowering period of the basil, which coincides with the mid-summer emergence of the pepper maggot on farms in the Northeast. Furthermore, populations of natural enemies were observed earlier in the growing season than herbivores in plots intercropped with aromatics, indicating the potential of increased biological control from stabilized predator populations that address pest issues before they develop into infestations (Beizhou et al., 2011).

Additional characteristics of *O. basilicum* also contribute to its potential success as part of the pepper maggot trap crop system. Because it is a shade-tolerant species, it is unaffected by the height of the other crops and will produce pollen, nectar, and aromatics consistently throughout the growing season. Pepper plants in production are primarily pollinated by bees, and it has been shown that they are highly attracted to *O. basilicum* (Souza et al., 2019). Finally, parasitoids, whose presence is highly dependent on their hosts and habitat, have been recorded in far greater numbers within intercrops involving *O. basilicum* than equivalent monocultures. This indicates that the diversification of habitat in such a manner can support a network of insects at higher trophic levels than would be possible in a simplified system (Souza et al., 2019).

Experimental Plan

It will be necessary to perform a field study with replicates to test this hypothesis. Four geographically separated southern New England farm sites must be selected to run this experiment. Preference must be given to sites adjacent to woodlands containing trees in the genus *Acer*, as maple trees are known to sustain *Zonosemata electa* populations. For each site, five half-acre plots, spaced 100m apart, should be utilized. Peppers should be grown separately on each farm in the spring and planted when the appropriate soil temperatures are achieved. Each of the five plots will be unique: a "control" plot with no perimeter trap crop and no insecticide applications, a plot with insecticide applications but no trap crop, a plot with a trap crop but without any insecticide applications, a plot with a trap crop with pesticide applications, and finally a trap crop containing an intercrop of *O. basilicum*. Insect populations will be recorded using sticky cards, strategically placed at even intervals throughout all the rows. Pepper maggot oviposition will be recorded by manually counting the sting scars on the peppers.

Proposed Results



Conclusions

These results, when considered together, indicate that the addition of basil to existing agroecological-based systems has the potential to stabilize beneficial arthropod communities while also reducing pest populations. Combining this intercrop with the established perimeter trap cropping system would decrease pepper maggot oviposition on bell pepper crops by facilitating the establishment of robust natural predator populations, which would provide another layer of defense and coincide temporally with pepper maggot emergence from the soil during the mid-summer months. The aromatic properties of *O. basilicum* could also provide a secondary “push” mechanism to the system by interfering with the olfactory cues which enable certain pests to locate target hosts. Due to a lack of empirical research data it is difficult to assess if this deterrent property would be significant with regard to *Zonosemata electa*, however it would likely apply to other common bell pepper crop pests and it is surmisable that the increased abundance of natural enemies and aromatic chemicals radiating from the interior of this system would naturally reduce oviposition and relegate the pepper maggot insects toward the peripheral cherry pepper trap crop.

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