INTRODUCTION
Plasticulture may be defined as the use of plastic in agriculture. The plasticulture system combines raised bed, plastic mulch and drip fertigation for field production of tomato, pepper, strawberry, cucurbit and other specialty crops (Fig. 1). In plasticulture systems, crops are transplanted or seeded into small holes punched into a mulch and watered via drip irrigation. This system provides conventional and organic farmers several benefits such as increased water and fertilizer use efficiency and early flowering. Producers such as fresh market tomato growers utilize a plasticulture production system to achieve earlier harvest and increased yields of high-quality fruit. Polyethylene mulches (PEMs) which are frequently used in plasticulture systems are also deployed to facilitate preplant fumigation, reduce water evaporation, and suppress weed establishment. Plastic mulches prevent weed seed germination and growth by inhibiting sunlight penetration. Plasticulture may be especially useful in cropping systems where weed management tools are limited during the crop’s cycle. For example, weed management can be particularly challenging in watermelon. The wide spacing between watermelon seedlings leaves large areas of the field bare early after planting. These open spaces can be exploited by weeds. Moreover, its vining growth habit and sensitivity to mechanical injury limits herbicide sprays and tillage to the early crop stage. As such, transplanting watermelon into PEMs can effectively control broadleaf and grass weeds at best within planting rows where interference with weeds would be most damaging. This is the 7th article of a series on IWM. Initial articles can be found within the Vegetable and Fruit and Headline News newsletter (March, April and May Special Editions).

PLASTICULTURE AND HERBICIDE MOVEMENT/DISSIPATION
Herbicide dissipation may refer to the period that herbicides stay active against weeds in the top six inches of soil. Weed control is typically required until the crop canopy closes. Thus, in general, it is hopeful that herbicides will stay active and onsite until crop canopy closure. However, several factors unrelated to farmers’ application method can influence herbicide soil persistence. For example,
herbicides applied to crops grown on sandy soils with low organic matter will favor herbicide movement. Rainfall or irrigation needed for crop establishment and growth can cause herbicides to leach. When herbicide effectiveness ceases before canopy closure, producers may need to apply a “rescue” management practice to suppress weed establishment. Plastic mulches may be used to extend herbicide effectiveness by delaying and reducing herbicide leaching. For example, for the pre-emergent herbicides linuron, pendimethalin and fluorochloridone, dissipation was reduced when applied to soil under perforated PEM cover compared with bare-soil applications; and the time required for S-metolachlor another pre-emergent herbicide that target annual broadleaf and grass weeds to dissipate 50% (DT50) increased from 2 to 4 days when the soil was covered with plastic mulch compared with bare-ground. Plastic mulches may influence herbicide dissipation dynamics by increasing herbicide persistence in the soil via: 1) limiting sunlight exposure, 2) reducing leaching from rainfall and 3) affecting biological activity. If a plastic mulch can extend the period that herbicides remain effective, this may eliminate the requirement of in-season weed management tactics later in the crop cycle. Thus, knowledge of herbicide dissipation in plasticulture systems can help producers institute best weed management practices.

**LIMITATIONS of PLASTICULTURE**

In general, plasticulture systems are a positive investment for producers of specialty crops and they work well in containing broadleaf and grass weeds. However, there are some issues using plasticulture to manage weeds. For example, weeds may emerge in planting holes and between raised beds (row middles) of plastic mulch. Weed seeds that germinate and establish in openings where transplants are placed can be especially problematic. The close proximity of weeds and crop plants sharing a confined area intensifies weed-crop competition. Thus, the recommendation in some crop plasticulture systems is to utilize the mulch in combination with herbicides and/or hand-weeding. For example, in strawberry production, it is recommended that broad-spectrum pre-emergent herbicides (PREs) be applied under the plastic mulch to reduce the need for in-season weed control measures. However, applying herbicides to areas below the mulch seems counterintuitive as it is there to prevent weed establishment within the crop row. Further, some weeds such as purple nutsedge (Cyperus rotundus) and yellow nutsedge (C. esculentus) penetrate PEMs. Consequently, holes and tears may facilitate the emergence of other weeds.

**Weed competition in transplant holes**

It is widely accepted that weed interference with vegetables in bare-ground production systems are greatest when weeds are in close proximity to crop. A goal of plasticulture is to prevent weed establishment in areas within crop rows. Still, weeds are capable of germinating and emerging within holes where transplants are transplanted. Weeds growing through planting holes can enter from below the soil or may be dispersed into planting holes via wind. A study was conducted to determine the impact of eastern black nightshade (Solanum ptycanthum) invasion of plant holes on tomato yield grown in plasticulture. Solanaceous weeds such as nightshade are closely related to tomato, thus control of this weed by herbicides is challenging without injuring tomato. Nightshade emergence in planting holes reduced total tomato yield by ~ 35% when the nightshade was transplanted into the plant hole one week after tomato transplanting (WAT) compared to 12 WAT. In this plasticulture system, it was concluded that the critical weed-free period to avoid >20% yield loss for extra-large and jumbo grade tomatoes was 28 to 50 d after transplant. The critical weed-free period is the minimum length of time that crops must be maintained weed-free after planting to prevent significant losses in crop yield or quality. The 50 d period required to control nightshade after tomato transplanting is long relative to other studies for bare-ground tomato. It was suggested that this weed is more competitive with tomato when grown in plasticulture. The increased crop-weed interference is tentatively due to the convenient supply of water and nutrients applied through drip irrigation that are being exploited by nightshade for maximum growth. Still, there was a lack of
differential effect on yield for one to five nightshade plants per hole. In another plasticulture study involving tomato, it was reported that weeds that emerged at tomato transplanting reduced marketable yield up to 65%.

Transplanted tomato plants may have an early season advantage over some weeds for space. However, a study showed that when grown together with Palmer amaranth (Amaranthus palmeri), transplanted, plasticulture-grown tomato must remain Palmer amaranth-free between 3 and 6 WAT to maintain marketable jumbo tomato fruit yields similar to the weed-free habitats. Findings from the former and latter studies agree with the assertion that weed presence close to a plant, especially within transplant holes, will reduce crop yield and quality. This reduction can occur via direct competition or by weeds modifying the environment to favor or attract pests and pathogens detrimental to the crop. In another study, Palmer amaranth was seeded at densities of 1, 2, 3 and 4 plants per watermelon planting hole and compared with a weed-free control (Fig. 2). Increasing Palmer densities caused significant reductions in marketable watermelon yield and fruit number. Four Palmer amaranth plants per planting hole reduced marketable yield 41, 38 and 65% for Exclamation, Carnivor, and Kazako varieties, respectively. Palmer amaranth seed and biomass production was similar across weed population densities, but seed number per female plant decreased. This suggest that increasing weed population densities caused an increased intraspecific competition among

**Palmer amaranth plants.**

In plasticulture systems, PREs are typically applied over the entire width of raised beds before laying the mulch. This is mainly done to prevent broadleaf and grass weed emergence in the mulch’s transplant holes. As a result, most of the herbicide application occurs in areas that are unnecessary because weeds cannot emerge. To reduce this wasteful application of herbicide, researchers at the University of Florida developed a precision hole-punch sprayer for use in plasticulture production systems. The technology facilitates the application of herbicides during the hole-punch operation immediately before transplant. The equipment was used to safely apply herbicides to plasticulture beds immediately before tomato and bell pepper were transplanted. Equipment accuracy in these crops ranged from 55% to 90%. More importantly, PRE use was reduced from 88 to 92% with no reduction in weed control. Future plans include improving the placement or accuracy of sprays.
**Plasticulture and nutsedges**

Purple and yellow nutsedge are present in every state within the US and are recognized as two of the most troublesome weeds in vegetable production. Both interfere with vegetable growth by competing for sunlight, water and nutrients. Further, both are particularly difficult to control in plasticulture because their sharp leaf tip and strong midrib allows these plants to puncture plastic mulches (Fig. 3). Nutsedge shoots can easily penetrate standard low-density polyethylene (LDPE) mulch, regardless of color and it was reported that nutsedge is capable of penetrating plastic mulch four times thicker than commonly used commercial mulches. Further, stretching of plastic mulch by tractor implement during application to beds may further lessen the ability of PEMs to resist nutsedge shoot penetration. Moreover, tears and holes in PEMs caused by nutsedge allow other weeds to germinate. Hand-weeding of nutsedge that emerges through mulch is labor intensive and weeding can enhance production cost

Though purple nutsedge can poke through PEM, it has been reported that yield reduction is mainly from below-ground competition. In a study, it was found that below-ground interference accounted for 64% of the shoot dry weight reduction in tomato. Further, some plasticulture systems can amplify a nutsedge problem. A study evaluating the impact of PEM on purple nutsedge found that its underground patch size increased under PEM and covered almost twice as much area compared to the non-PEM control. Moreover, studies have demonstrated that root exudates of purple nutsedge have an allelopathic effect on the root and shoot growth of tomato plants. Nutsedges may also reduce the “shelf life” of mulches. Plastic mulches are typically used in several crops before they are destroyed. Howbeit, hole punctures caused by nutsedges hinder their use in sequential crops, creating an additional cost.

**Paper mulch and the nutsedge challenge**

The trend towards eco-friendly production techniques has resulted in an interest in biodegradable paper mulches. Another keenness in paper mulch is their potential to suppress weeds, with specific interest in nutsedge. This curiosity has led to several studies evaluating their weed suppressive ability. One study showed that coated paper mulch can reduce nutsedge pressure in pepper. Similarly, other studies have shown that paper mulch is one of the few mulches that can effectively suppress nutsedge. For example, paper mulches were found to prevent penetration by sharp nutsedge shoots and effectively controlled purple and yellow nutsedge in tomato and watermelon, respectively. It was suggested that paper mulch used in another study did not prevent purple nutsedge emergence from the soil. However, it resisted its pressure without breaking, which prevented nutsedge plants from piercing through. These results were witnessed under circumstances of low-rainfall. As such, it was proposed that the paper mulch may lose efficacy if evaluated under high-rainfall conditions. Still, an important advantage of paper compared to PEM is its ability to control purple nutedge. Despite being biodegradable and having acceptable weed suppression and yield in most instances, paper mulch has not become a commercial alternative to PEM due to heavier reels, slower mulching speed and the need of a careful handling to avoid tears during installation. Further, some paper mulches deteriorate rapidly under field conditions, reducing their effectiveness. Additionally, paper mulches are inherently more expensive than PEM. However, this cost may be supplemented due to savings in removal and disposal as well as environmental gains compared to PEM usage.
Biodegradable plastic mulch (BDM)

Despite the significant horticultural benefits of PEM for specialty crops, their removal and disposal require labor and financial investments. Burying or tilling PEM can lead to groundwater and soil contamination with plastic byproducts and microplastics that can persist in the soil. While mulch recycling is available in some regions, it is limited in others and adds to growers’ disposal costs for transport and cleaning. Recycling difficulties have led many growers to stockpile or dispose of their plastic through local landfills. Others may burn their plastic waste, which has deleterious effects on the environment and human health. Further, temperature stress imposed on plants in warm climates with black PEM can also be an issue. These problems have contributed to research interest in biodegradable plastic mulch (BDM; Fig. 4).

Introduced in the 1990s, BDM is a potential alternative to PEM. It has similar horticultural benefits but does not have to be removed from the field at the end of the growing season. Made from starch and other biodegradable polymers, BDM is designed to perform comparably to PEM while also biodegrading in the soil or composting area at the end of its use. To this point, BDMs can be tilled into the soil or retrieved and composted where it is converted by soil microorganisms into water, carbon dioxide and microbial biomass. Thus, BDM can be used to manage weeds without harboring some of the economic, environmental and human health constraints posed by PEM. Depending on the specific product, BDMs have been found to completely deteriorate within soils after 13 months of incorporation and have produce yields comparable to crops grown with PEM. The long-term environmental impacts of BDM require further investigation. Nevertheless, it is recognized as a possible method of reducing agricultural plastic pollution.

Similar to PEM, both nutsedge species can penetrate BDMs. A two-year experiment was conducted in TN to investigate pepper production in five different BDM types. The BDM treatments included one white-on-black and four blacks. The BDMs were compared with a black PEM, one brown creped, paper mulch, and a bare-ground control treatment. Most mulches were degraded, with 40% to 60% of the soil exposed by the end of the season, with the exception of the paper mulch, which was completely degraded at the end of both seasons. Weed pressure was severe during the study largely due to early penetration of mulches by nutsedge. Due to early and season-long weed pressure and heat stress in black mulches, there were fewer healthy pepper plants and reduced yields in all black-colored mulch treatments in year 2. The paper mulch was the only mulch treatment that prevented nutsedge penetration. Therefore, this treatment and the hand-weeded bare-ground treatment had the greatest yields in year 2. The white-on-black BDM treatment also had yields comparable with paper mulch and bare-ground plots in year 2. It was proposed that the cooling effect of the white mulch contributed to the yield advantage. These results suggest that in hot climates and in fields infested with nutsedge, paper mulches perform best due to cooling effects and superior weed control.
Weeds between raised beds

Weeds germinating in transplant holes of plastic mulches are a known issue. However, in plasticulture vegetable systems, weeds emerging in the area between raised beds are typically the most difficult to manage. Though separated spatially from the crop, weeds in the row middle can reduce crop yield and quality. Further, some of the vining weeds such as morning glory can creep onto the mulch and climb crops. Moreover, weeds between beds can host nematodes, pathogens and insect pests harmful to the crop, as well as reduce harvest efficiency. Growers rely mostly on herbicides to manage weeds between beds in plasticulture, as cultivation can be challenging due to the mulch. When weeds have already emerged, some crop advisors may recommend tank mixing a post-emergence (POST) with a PRE. Thus, many growers apply a POST such as glyphosate or paraquat before planting; and in some instances, the POST is tank-mixed with a soil residual herbicide. However, multiple herbicide applications are required to achieve season-long weed control, and the number of applications differ between fields and seasons. Notwithstanding, applications of herbicides after planting are more difficult because of the limited number of registered products and risks of herbicide drift. A more ecofriendly solution may be growing a living mulch in the soil area between raised bed (Fig. 5). Though some recent research was conducted at Cornell University, not much research has been conducted on the use of living mulch in plasticulture systems. Howbeit, this is an area that should receive more research awareness as research has demonstrated the ability of living mulches to suppress weeds in the between row area of vegetable crops in non-mulch fields.

SUMMARY

Black PEM is extensively used in plasticulture because of its low cost and ability to help manage weeds, conserve soil moisture, modify soil temperatures, as well as initiate early harvest and increase crop yields. These advantages can be extended to organic producers, if the mulch is removed from the field once the growing season is complete. However, disadvantages include weeds poking through the planting holes and occurring between the mulch beds, temperature stress in warm climates with black mulch, as well as removal and disposal costs. Potential environmental and human health impacts associated with their disposal and destruction is of particular concern. Still, many of the shortcomings can be addressed by using biodegradable paper and plastic mulches. Although there are several challenges to using polyethylene mulches in plasticulture systems, benefits such as overall weed suppression may supersede the negative aspects. Thus, plasticulture systems will continue to be an integral component of weed management programs in specialty crops.

Financial support for the publication of this article is via USDA NIFA AFRI CARE and EIPM grant award numbers 2016-68008-25079 and 2017-70006-27171, respectively. Reference to trade names mentioned in this article is made with the understanding that no endorsement or criticism is being made towards those products by the University of Maryland. Mentioning of trade names or products was made solely for educational purposes.
Introduction
Insect pollinators play an essential role in the maintenance of wild plant diversity and agricultural productivity. Indeed, global studies have shown that the vast majority of plants require animal pollination to produce fruit and seed. In temperate regions, major pollinator groups include bees (Hymenoptera), syrphid (Diptera), as well as butterflies and moths (Lepidoptera). In contrast to bees, Lepidoptera are not considered efficient pollinators of most cultivated plants. Nevertheless, they are vital pollinators of many flowering plants, especially in the wild as well as managed lands such as parks and yards.

The pollinating taxa of Lepidoptera are mainly in the moth families Sphingidae (hawk moths; Fig. 1), Noctuidae (owlet moths) and Geometridae (geometer moths), and the butterfly families Hesperiidae (skippers) and Papilionoidea (common butterflies). The adult stage of these lepidopterans obtains their nutrients and water from nectar of various flowers; and while exploiting flowers for food, pollination may occur. Moths and butterflies have different pollinator niches, as butterflies are very active during the day (diurnal) and visit open flowers during the morning hours and under full sunlight. Contrarily, moths are more active during the evening and night hours (nocturnal). As a response to this, some flowers may seek to increase pollination by changing color during a 24-hour period to attract butterflies during the day and moths at night. For example, Quisqualis indica flowers change color from white to pink to red which may be associated with a shift from moth to butterfly pollination (Fig. 2). A study conducted in China verified that different pollinators are attracted to each floral color stage; primarily moths at night and bees and butterflies during the day. Further, fruit set was higher for white than pink or red flowers indicating that moths contributed more to its reproductive success. While adult butterflies and moths are important pollinators, their larvae – often called caterpillars – may be economically important pests in agricultural, forest and urban environments. In some instances, their status as agricultural villains as caterpillars override their positive image as ecosystem service providers as adults.

Nectar and pollen consumption
Adult butterflies diet choice varies between species, populations, generations, sexes, age groups and individuals. Most adult lepidopterans feed on fluid resources such as nectar, decomposing animals, dung and fruit sap (Fig. 3) and others may not feed at all as adults. Butterflies consume nectar by active suction using their elongated mouthparts (called proboscis), and usually avoid highly concentrated nectar because of its high viscosity.
Nutritionally, nectar serves as a source of water, carbohydrates and amino acids; the latter allowing butterflies to meet their nitrogen requirements. Interestingly, butterfly-pollinated flowers tend to have higher concentrations of amino acids than do flowers pollinated by bees and other animals. This is remarkable since insects like butterflies, whose larval stages feed on plant foliage and adult stages on nectar have long been assumed to obtain most or all of their nitrogen-rich compounds needed for reproduction from larval feeding. Going against this assumption, it has been shown that both nectar consumption and larval food intake can affect the life span and fecundity (number of offsprings produced) of some butterfly species. For example, a recent study found that nitrogen-rich compounds (amino acids) present in nectar significantly increased the fecundity of the nectar-feeding butterfly Araschnia levana. However, their fecundity was enhanced only if the female fed on a poor-quality plant as a larva. This suggests that nectar can act as a necessary dietary complement if a butterfly fed on a nitrogen-poor plant as a larva.

Another nitrogen-rich floral reward is pollen. Nectar-consuming butterflies come into contact with pollen while visiting flowers, but the vast majority of butterflies is unable to feed on pollen. However, butterflies of the neotropical genera Heliconius and Laparus (Lepidoptera: Nymphalidae; Fig. 4) evolved a feeding technique in which amino acids are extracted from pollen grains, rather than fortuitously during their pursuit of nectar. These butterflies collect and accumulate large pollen loads, and the production of saliva helps keep it attached to their proboscis while they gently chew the pollen to consume its amino acids. Pollen feeding is thought to increase Heliconius longevity and egg production.

**Butterflies efficiency as pollinators**

It has been suggested that for most plant species, butterflies visit flowers less frequently than bees and deposit less pollen per visit. With a few notable exceptions such as yucca moths, adult lepidopterans show little floral specialization, preferring flowers with large landing surfaces, deep, narrow corollas that can accommodate their elongated mouths, and plants displaying many flowers in close proximity. Butterflies prefer visiting large flower heads, and when searching flowers for nectar, pollen grains attach to various body extremities (e.g., mouth parts, head) depending on the plant's floral architecture. However, because butterflies' legs and mouth parts are elongated, most of their body does not enter in direct contact with the plant's pollen. Consequently, butterflies pick up less pollen on their bodies than bees, and most of it is usually deposited on or around their heads and mouth parts. This pollen is then transferred to the surface of the stigma when the butterfly reaches for nectar in a new flower. Because little pollen is usually carried by butterflies, and the fact that – unlike bees – they don’t have specialized structures for carrying pollen, butterflies are less successful than bees at moving pollen between flowers. Although not as efficient as bees, butterflies can be very effective pollinators, and among the insect fauna they qualify as essential pollinators. In many instances, a decline in the butterfly fauna is attributed to a decrease in nectar-rich and economically
or culturally important wild plant species. Further, butterflies can be important in agricultural systems. For example, a survey of pollinators associated with macadamia in NE Brazil found that macadamia yields mainly benefited from pollination by butterflies rather than bees. Consequently, butterflies were responsible for > 50% of floral visits to macadamia flower. Moreover, their pollination of some vegetable crops contributes strongly to seed production.

Many flowers, including some orchids, are completely dependent on butterflies for pollination, and a member of the pea family, the peacock flower (Caesalpinia pulcherrima; Fig. 5) is largely dependent on butterflies for pollination, with pollen being mainly carried on their wings. In addition to butterflies, some moths have a special relationship with specific plants. For example, the yucca plant (Hesperoyucca whipplei) is pollinated by the yucca moth (Tegeticula maculata) with which it has a symbiotic relationship. The gravid female moth gathers pollen grains from flowers at night and forms them into a ball. She carries the ball in her mouth to another yucca flower. She then inserts her ovipositor into the ovary wall of the flower and deposits a single egg and then pushes the pollen into the stigma, thus pollinating the flower. The larva hatches in late spring or summer, and feeds on some of the developing seeds. Emergence of the adult moth occurs while yucca plants are again in bloom, allowing the cycle to continue.

**Flower structure and mouthparts**

The body architecture (e.g., body size, mouth shape) and behavior of pollinators with respect to the flower’s dimension and morphology, are some of the factors that define which floral visitors are effective pollinators. Many studies of plant-pollinator interactions provide evidence that the morphological match between the flower shape and size, and the length of pollinators’ mouthparts influences pollination success.

In relation to this, it has been observed that flowers and their pollinators engage in a series of reciprocal adaptive or coevolutionary cycles. In these cycles, plants that have the “best” floral shape for a specific pollinator are capable of producing more seeds, while pollinators that are capable of obtaining more nectar from an individual flower visit will also obtain greater energy required to produce more offsprings. When the pollinator and plant requirements align like this, plants tend to evolve floral shapes that match their “best” pollinator, while pollinators tend to evolve specific floral preferences and morphologies that match the plant. Over many generations, this leads to the establishment of floral preferences in pollinators, and a convergence in floral shapes of flowers visited by a given type of pollinator. It is for this reason that butterflies and hummingbirds are seen more often visiting long-necked or trumpet shaped flowers, than other pollinators; and these flower types are better pollinated by butterflies or hummingbirds than other pollinator groups. The result of these coevolutionary processes can be seen in many cases of pollination, but some of the most impressive examples are those having led to the evolution of extremely long proboscides (up to 14 inches) in some lepidopterans (Fig. 6), which match the length of the floral tube of their preferred flowers.
How do moths and butterflies locate flowers
In order to locate floral resources, lepidopterans use a series of cues, such as specific colors, shapes, sizes and odors. As stated previously, moths are major nocturnal pollinators of a diverse range of plant species but have been historically considered to contribute little to overall pollination. However, recent research has rejected this notion, demonstrating that nocturnal moths contribute strongly to pollination, even to the point of compensating for poor pollination by diurnal pollinators. Moths are attracted to pale or white flowers with an open cup or tubular shape, heavy with fragrance and dilute nectar, and typically open in late afternoon to night. In turn, these plants are also specialized in pollination by moths, with these attractive traits having evolved through millions of years of coevolution. An example of these plants includes the creeping buttercup or honeysuckle, which tend to emit a strong fragrance at night.

Unlike moths, butterflies are diurnal and typically visit flowers under heavy sunlight, preferring those displayed in clusters and offering large nectar rewards (Fig. 7). Flowers specialized in pollination by butterflies are often brightly colored (red, yellow, orange), lack an apparent scent and secrete relatively dilute nectar in narrow elongated floral tubes. Examples of butterfly flowers are goldenrods and Asters, which provide a large landing surface as well as abundant and accessible nectar. Some of these preferences in butterflies are due to the butterfly’s good perception of color, which in most cases covers a wider range of the spectrum than human vision. Indeed, various studies have demonstrated that some pollinators rely strongly on color to make their foraging decisions, and this is certainly the case of butterflies. Similar to hummingbirds, butterflies have a good perception of the color red and as such, are attracted to red flowers. Further, many lepidopterans are able to distinguish various shades of yellow. To this point, an experiment consisting of potted daylily and nightlilly showed that swallowtail butterflies preferentially visited reddish or orange-colored flowers and hawkmoths favored yellowish flowers. Similar to many insects, butterflies are capable of seeing ultraviolet light, which allows them to follow special nectar markings present on flowers that are only visible under that type of light. Correspondingly, to how butterflies and moths are able to sense odors of their preferred flowers, studies have shown that butterflies may also sense the nectar amino acid content of different flowers, preferring those with high versus low amino acid content. For instance, studies found that, when given the choice, the cabbage white butterfly (Pieris rapae) preferred feeding on artificial flowers containing sugar-amino acid mixes, versus sugar-only nectar of Lantana camara (a perennial shrub).

**Butterfly flower avoidance**
As with all organisms, butterflies have their own natural enemies at the immature and adult stages. Egg, larva and pupa of butterflies and moths are vulnerable to parasitism and predation. Adult stages may suffer mortality from mammalian and arthropod predation. For instance, when visiting flowers, butterflies may be vulnerable to arthropod predators such as mantises and spiders (Fig. 8).
Studies have shown that butterflies are capable of avoiding flowers with predator cues. For example, similar to bees, they have been shown to avoid flowers with artificial spiders and models of spider forelimbs. In another study conducted in a butterfly pavilion, visiting butterflies stayed away from flowers containing dead mantises. Howbeit, it is debatable whether butterflies were responding to the mantis’s cues or were simply avoiding flowers containing foreign objects. Still, some studies seem to agree that at least some avoidance is due to visual recognition. Interestingly, the degree of avoidance recorded in these studies indicated that it was weaker in butterflies reared in the pavilion than in wild butterflies. This tends to indicate that a part of this avoidance is learned and a reflection of previous predation experiences.

Butterfly conservation
Drivers of pollinator and butterfly losses. Many insect pollinators that provide vital services are declining and multiple factors have been implicated. In Europe, noticeable drops have been observed for butterflies, wild bees and hoverflies. Similarly, lepidopterists in the US are reporting that butterflies are in decline. Butterflies face a wide range of threats including habitat loss, changes in land management and land use, climate change, disease, pesticides and invasive organisms. Another driver of pollinator decline is agriculture intensification, which results in loss and fragmentation of pollinator-diverse habitats such as semi-natural grasslands, and is also associated with increased chemical use. Other factors associated with human activity have also been identified as contributors to pollinator loss. For instance, pollutants and urbanization can negatively affect the richness and abundance of native plant species used by pollinators, and thus lead to poor pollinator communities. Anthropogenic changes in the landscape can sometimes affect pollinators in surprising and indirect ways. For instance, changes in land use can lead to increased encroachment of plants such as some shrubs that are not congenial to butterflies and an associated decrease in butterfly richness and abundance by negatively impacting herbaceous plant cover and diversity. Further, enhanced shrub covering may indirectly affect pollinators by increasing their predation by perching birds.

Should bee and butterfly conservation plans be the same? The ecology of lepidopterans differs from that of bees. For example, bees require nectar and pollen throughout their life, while butterflies only utilize nectar as adults. Further, most caterpillars are leaf-feeders and do not require any parental care, while bees must collect pollen and nectar to support their brood and themselves. Moreover, while most bee species develop in relatively protected habitats (i.e., their nests), caterpillars are exposed while feeding on their host plants, vulnerable to predation, parasitism and climatic factors. These differences may require some alterations in conservation efforts aimed at protecting butterflies and bees. For example, butterfly-friendly environments must contain plants that support the larval and adult stages, and land management practices need to be appropriate for preserving plant species needed in caterpillar diets. Failing to do so would lead to low caterpillar survival or death, and the eventual loss of the butterfly population.

Conserving butterflies. To help save butterflies and other pollinators, it is recommended that a diversity of colorful, wildlife-friendly plants full of nectar be planted in gardens, yards, urban and recreational areas and on/nearby arable lands. Floral diversity is a pre-requisite for enhancing butterfly conservation, especially in urban environments. To better ensure butterflies have access to resources throughout the year, flowers with a range of bloom time (early spring through fall) and morphological features should be planted. Further, a habitat hospitable to butterflies and moths provides food for caterpillars, nectar-bearing flowers for adults, and consists of at least some native species. Indeed, although a few can feed on exotic plants, most caterpillar species are specialized on native plant species. Likewise, although some caterpillars are polyphagous, most are restricted to a few or just one plant species. Protecting land for butterflies does not equate to transforming all land
into a fully protected area. Indeed, land in public settings, such as roadway medians, roadsides, landscaped parks, and even railway embankments have the potential to support large populations of pollinators. Confirming this, studies found that bee and butterfly species richness and abundance were higher in railway embankments than in grasslands. Further, they demonstrated that in that context non-vegetated ground negatively affected butterfly populations, since their diversity positively depended on species richness of native plants. For this same reason, open forests also tend to harbor higher pollinator diversity than forests with a very closed canopy. Further, actions can be taken to improve the pollinator friendliness of different public lands. For instance, roadside management plans can be designed to benefit pollinators (Fig. 9). Roadsides with abundant and diverse native wildflowers managed with judicious mowing and herbicide use can become diverse pollinator habitats. Furthermore, research indicates that roadsides with high-quality habitat reduce pollinator mortality as insects remain in the roadside as opposed to leaving in search of flowers.

Land management tactics for increasing plant diversity (intercropping, cover cropping, insectary plants, flower borders, etc.) are often used to enhance populations of natural enemies in cropping systems. When this practice is used to augment natural enemy efficacy, it is often called conservation biological control. However, this same tactic can be used to concomitantly conserve biocontrol agents and pollinators, while enhancing other services to cropping system (i.e., pest suppression). In a similar context, the idea of companion planting can also represent a way to combine production with pollinator protection in agricultural landscapes. Companion planting is a traditional husbandry practice whereby a second plant species is planted alongside a crop with the goal of improving yield. Using a flowering species as a companion plant can make arable lands more congenial to pollinators resulting in improved pollination services and crop yield. A recent study examined the use of borage, Borago officinalis (Fig. 10), as a companion plant in strawberry. Borage plants were found to significantly increase yield and quality of strawberries, suggesting an increase in insect pollination per plant.

**Summary**

Immature stages of some moths and butterflies are viewed negatively because of their harm to agriculture. However, adult lepidopterans are mostly cherished for their aesthetic beauty, and less recognized for their contribution to pollination. Howbeit, lepidopterans are vital contributors to the pollination of wild plants and domesticated crops; and though their efficiency at crop pollination does not reach the level of bees in most systems, there are instances in which their services are of greater value (as for pollination of macadamia nuts), or compensating diurnal pollination (as shown for nocturnal moths). Moreover, while bees are more likely to pollinate fruit crops, butterflies are primary pollinators for many vegetables and herbs, especially those in the carrot, sunflower, legume, mint and Brassica family. Although pollination of these vegetable crops is not needed for producing the edible portion of the crop, it is required for seed production, in which future plantings require. This suggests that efforts being directed to protect bee pollinators should similarly integrate moth and butterfly conservation. To this point, because the ecology of bees and lepidopterans differ especially with respect to resource requirements during their immature stage, plans directed at conserving bee and lepidopteran pollinators should take these differences into consideration.

Financial support for the publication of this article is via USDA NIFA EIPM grant award numbers 2017-70006-27171.
**Vegetable & Fruit News**

A timely publication for the commercial vegetable and fruit industry available electronically in 2020 from April through October on the following dates: **April 16, May 14, June 11, July 9, August 13, September 10 and October 29 (Special Research & Meeting Edition).**

*Published by the University of Maryland Extension Focus Teams: 1) Agriculture and Food Systems; and 2) Environment and Natural Resources.*

**Submit Articles to:**
Editor,  
R. David Myers, Extension Educator  
Agriculture and Natural Resources  
97 Dairy Lane  
Gambrills, MD 21054  
410 222-3906  
myersrd@umd.edu

**Article submission deadlines for 2020 at 4:30 p.m. on:** April 15, May 13, June 10, July 8, August 12, September 9 and October 28 (Special Research & Meeting Edition).

Note: Registered Trade Mark® Products, Manufacturers, or Companies mentioned within this newsletter are not to be considered as sole endorsements.  
The information has been provided for educational purposes only.

*The University of Maryland Extension programs are open to any person and will not discriminate against anyone because of race, age, sex, color, sexual orientation, physical or mental disability, religion, ancestry, national origin, marital status, genetic information, political affiliation, and gender identity or expression.*