Monterey County's Agricultural Field Plastic: An assessment and way forward

How much field plastic is used?

Is agricultural plastic found in waterways?

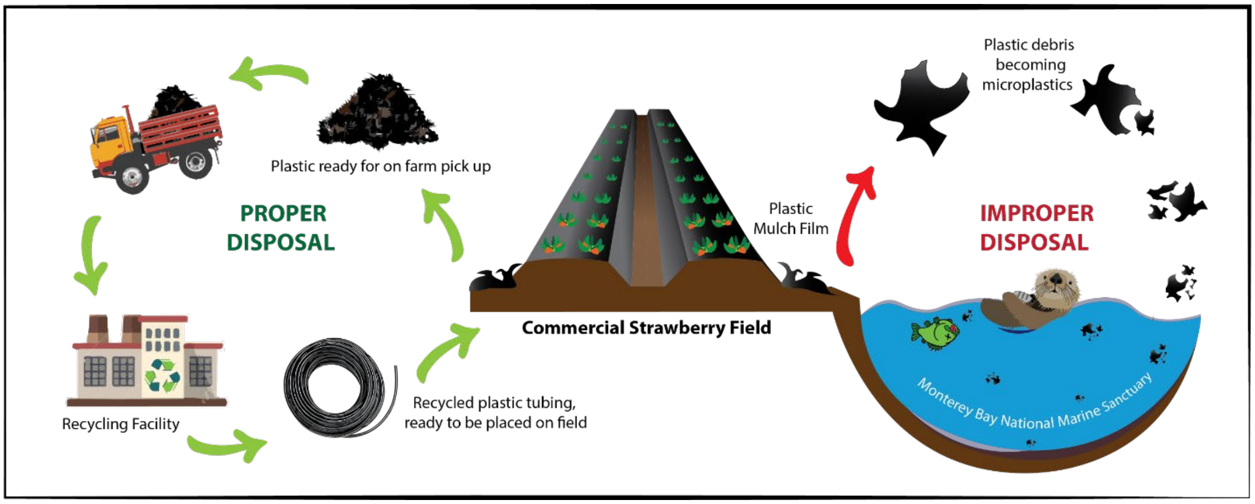
What can stakeholders do to reduce plastic pollution?

California State University
MONTEREY BAY

California Marine Sanctuary Foundation

National Marine Sanctuaries
Monterey Bay

AGRICULTURAL USE OF PLASTIC IN MONTEREY COUNTY: AN ASSESSMENT OF PLASTIC POLLUTION RISK AND REDUCTION FOR REGIONAL WATERWAYS



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EXECUTIVE SUMMARY

The Monterey Bay National Marine Sanctuary (MBNMS) is concerned with the amount of plastic pollution from all sources that enters the marine environment, both locally and globally. Agriculture production is a dominant industry within MBNMS watersheds, and the impact of agriculturally sourced plastic requires solutions to prevent plastic from entering waterbodies that transport pollutants to the ocean. The California Marine Sanctuary Foundation (CMSF) partnered with MBNMS to address three questions: 1) How much plastic is used in Monterey County crop production and what end of life strategies are available locally? 2) What kinds of plastic pollution from agriculture are evident in local waterbodies? 3) What can agricultural stakeholders do to help reduce the plastic pollution problem?

Many advances in agriculture have been made possible through the use of plastic. These include longer growing periods, more efficient resource utilization, labor savings, increased crop quality and yield, as well as lowering agrichemical use. Agricultural plastic use is predicted to increase as human population increases. While plastic use is increasing, knowledge and understanding of the extent of plastic pollution in the soil, sea and air is in its early stages, with toxicological and long-term system impacts still largely unknown (GESAMP 2015). Nevertheless, there is general agreement that the current rate of export of plastic to the environment is not sustainable and that all sectors of industry must find means to reduce the plastic load escaping into the environment. While agricultural plastic represents a small percent of the total plastic used, about 2-4% or 6.7 million tons in 2017 (Jansen et al. 2019), its presence in open fields where it is exposed to the effects of sun, water and wind make it especially vulnerable to transport into the non-agricultural environment, including the ocean. Chemicals including pesticides adhere to plastic, thus escaping agricultural plastic can convey pesticides to the ocean. For these reasons, intensified efforts need to be made by researchers, equipment manufacturers, resource conservation professionals and growers to find ways to more completely collect, replace, and recycle agricultural plastic.

Four major types of field plastic (drip tape, plastic mulch, fumigation film and hoop house plastic) used in food crop production in Monterey County were assessed to understand what types of plastic are most at risk for being transported to the ocean. This study estimated 10,000 tons per year is currently used on fields in Monterey County: drip tape (6095 tons/yr), polyethylene (PE) mulch film and totally impermeable film (TIF) used in fumigation (3971 tons/yr), and hoop house plastic (300 tons/yr). Actual agricultural field plastic use is higher than represented by these 4 plastic types, as supply containers, nursery plastic, pest barriers, irrigation PVC & tubing, onfield packaging, ditch lining and other types were not included in our estimates. Also excluded were agricultural production for cannabis, nursery and flower industries. In 2019 MRWMD land-filled 5698 tons of agricultural plastic (MRWMD 2020). In addition to estimating plastic use, we reviewed locally available options for recycling and replacing each type of field plastic.

Drip irrigation tape is the highest plastic use by weight in field crop production because it is widely applied to most crops, including artichokes, leafy greens, cole crops, orchards, grapes, strawberries and cane berries. Drip tape conserves water, saving up to 80% of the water used by other irrigation systems (Shrader 2000). It also provides a means to apply chemicals directly to the plant root and therefor reduce chemical use (Shrader 2000). This study estimated 6095 tons per year of drip tape is used in Monterey County crop production, with leafy greens, grapes and cole crops representing the highest acreage planted and highest amount of drip tape use. Recycling of drip tape is available in Monterey

County through local recyclers and suppliers. However, knowledge regarding what plastic types can be recycled and how to connect with recyclers for pick-up or delivery is not widely known in the grower community.

Film, including both mulch and fumigation film, represented the second highest plastic use in Monterey County crop production, totaling 3971 tons per year. Plastic mulch is a thin polyethylene (PE) film placed over the soil to prevent weed growth, influence soil temperature, and avoid edible crop contact with the soil. Film is primarily used in strawberry, cane berry and some specialty crop production, such as peppers and squash. Although it is used on fewer crops, the weight of film adds up to a significant number of pounds per acre in those crops that do use it. Film varies in thickness between 1 to 6 mils and in weight from 209 to 1204 lbs/acre. In conventional strawberry production, about 60% of acreage uses both fumigation and mulch plastic film (Bolda personal comm.). If both are used, film plastic amounts to 670 lb./acre over the crop cycle. Film cannot currently be recycled at any facilities near Monterey or Watsonville, and agricultural film is taken to the Regional Waste Management District, where it is added to landfill. Biodegradable mulch (BDM) is an alternative that provides the same benefits as PE mulch at a similar cost (Miles 2019). BDM may be a viable PE mulch replacement for local production, but remains to be tested under California growing conditions and crops. BDM has not been tested for use with fumigants, and may require reformulation to meet TIF standards. No current BDM products have been approved by the National Organic Standards Board (NOSB) for organic use in the US, however BDM is approved for organic use in Australia and Europe. BDM trials are proposed to begin soon in local strawberry fields.

Hoop houses are used locally in cane berry production, to start plants and to extend the growing season. Hoop house plastic amounts to about 300 tons per year in Monterey County for food crops, not including the amount used in greenhouses, nurseries and cannabis production. The plastic typically lasts 3 years, is accepted by Encore Recycling, and may be accepted by other suppliers or recyclers at the end of its useful life. This recycling option should be publicized to insure growers are aware that recycling is possible and how to arrange for pickup or delivery.

The second question addressed was “What kinds of agricultural plastic are entering local waterbodies that convey pollutants to the ocean?” Plastic pollution in the ocean is well documented environmental problem; however, agricultural plastic’s contribution is not well understood(GESAMP 2016). Microplastics (fragments < 5 mm) in Monterey Bay are found at all depths in the water column, and macro plastic has been found deep in the marine canyon (Choy et al. 2009, Schlining et al. 2013). Microplastic (MP) is ingested by the lowest trophic levels, and is conveyed up the food chain through pelagic and benthic foodwebs to such key fauna as sea turtles, sea birds, marine mammals and tuna (Choy et al. 2009). MP has entered the human food chain and is found in fish and clams sold for human consumption (Rochman et al. 2015, Forrest et al. 2018). Macroplastic causes multiple problems for marine animals, including entanglement and ingestion when mistaken for food, which can lead to gut blockages, nutrient deprivation and starvation (Pierce et al. 2004, GESAMP 2016). To discover whether agricultural plastic is entering waterways draining to the ocean, we conducted bank trash surveys as well as MP monitoring of waterways in agricultural landscapes in Monterey County. MP particles were found in all streams sampled, at concentrations of the same magnitude as MPs found in Monterey Bay by the Monterey Bay Aquarium Research Institute (MBARI). MPs in fresh water samples included fibers, fragments, films and pellets at combined concentrations ranging from 1.1 to 60.9 particles/m^3. MBARI found MP concentrations from 2.9 to 15 particles/m^3, with the highest concentration at 200 meter depth (Choy et al. 2019). The stream bank trash surveys revealed the highest density of agricultural plastic was film fragments, present in an average density of 1.73 pieces/m^2. Other agricultural plastic found during bank trash surveys included strapping tape, produce packaging, personal protective equipment (hairnets and gloves), drip tape, PVC pipe and drip tubing. A CSUMB 660 class survey of MPs at 3 agricultural sites and 3 urban outlets to the ocean in Monterey County found a higher concentration of MPs in urban outlets; however, a higher MP load was transported to the ocean from agricultural sites because of higher discharge rates from agricultural sources (CSUMB 2019).

Call to Action: *Because there are so many types of plastic used in agriculture with different end-of-use options, an effort should be made to make it easier for growers to responsibly purchase, completely remove, properly dispose of, and recycle or replace agricultural plastics. The importance of plastic use to agriculture in the context of natural resource management and agricultural productivity is undeniable, as is the need to responsibly manage plastic disposal so that it does not degrade on the field or enter local water systems where it can be transported into the Monterey Bay National Marine Sanctuary and the Pacific Ocean. This responsibility for progress rests not only with the grower and grower organizations, but also with the plastic product manufacturers, regional governments, recycling companies, sustainability collaboratives, and technical service professionals who assist growers with implementing technology and management practices. Ultimately, with appropriate education and product packaging, consumers too could be made a critical link in protecting the ecosystems of Monterey County and its treasured Marine Sanctuary.*

INTRODUCTION

Plastic use is ubiquitous throughout the globe, used in every nation, nearly every culture, across all professions and by all ages of people. It is used throughout industries from construction, to production, to space travel, to agriculture. It is used in transportation, in homes, in utilities and to clothe our bodies. Since its invention in 1907, the types, characteristics, forms, properties and uses of plastics have expanded so rapidly and so thoroughly into our lives and societies, that it is hard to imagine how we could live without it. Indeed, it could be argued that the rapid expansion of populations, industry and agricultural production would not have been possible without the durability, strength, low cost and multiplicity of types and properties of plastic that have been developed. Yet these very qualities that make plastic so desirable and arguably irreplaceable, have also created a long-term problem for humanity as the plastic pollution problem extends to our beaches, parks, roadsides and even beyond, to the areas uninhabited by humans. Macro and microplastics are found in Antarctic ice, the deep marine canyons of the ocean, on the shores of islands in the middle of the vast Pacific Ocean, and all strata in Monterey Bay. Plastic is stockpiling in our dumps at the same time that it is being discarded to the open environment. Every year the abundance and diversity of plastic is growing in the soils, fresh-water systems, and oceans, in the air we breathe and even the fish we eat (GESAMP 2015). A review of 42 studies of ocean sediments found 13 types of plastic polymers, the most predominant was polyethelyene (PE) found in 79% and polypropylene found in 64% of ocean sediments sampled (GESAMP 2015).

The unintended consequences of extensive plastic entry into the environment, although not entirely known, can no longer be ignored. Not all plastics are toxic to humans and other biota; however, some plastics are directly toxic, others leach toxic monomers and additives, and toxic chemicals adhere to many plastics, which then serve as a vector for their transport (Wang et al. 2018). Directly toxic plastics include BPA, which disrupts endocrine function, and styrene and vinyl chloride monomers, which are carcinogenic and mutagenic. Toxins that adhere to and are transported by plastics include PCBs, PAHs, HCHs and DDTs (Wang et al. 2018). As plastic breaks into smaller and smaller fragments and eventually weathers in the ocean and the soil, it becomes mistaken as a food source to organisms of different sizes and is conveyed up the food web (Cole et al. 2011). Plastic is found in the guts or tissues of all trophic levels in the ocean including zooplankton, mussels, barnacles, amphipods, fish, birds and marine mammals (GESAMP 2015). People ingest plastic present in water bottles, food packaging and prepared food and seafood.

Each industry and each community must grapple with how to make progress in recycling, replacing, reusing and reinventing methods to supplant or responsibly use and deal with the end of life issues of plastics. Each person must determine to make choices that take into account plastic content and disposal options associated with purchases. The plastic dilemma is part of the ethics of making purchasing and use decisions, made more difficult by lack of knowledge and difficulty of obtaining information. As a society, we face the issues of reconciling growing needs for crop production that depends on plastic use with the need to find ways to responsibly prevent harms to the environment and to ourselves from the escape to the environment of these ubiquitous chemicals. Many people in agriculture are working diligently to find solutions through such initiatives as full circle plastic uses that recycle spent product into the next new product, replacing plastic with biodegradable alternatives and preventing disposal methods that cause the greatest harm, such as burning, on-site dumping or burying. Yet the recycling rate remains low, and for some products there are few options other than disposal to landfills.

Although agriculture uses a relatively small proportion (2-4%) of the plastic produced globally, this use represented 6.7 million tons worldwide in 2017 and continues to grow (Jansen et al. 2019). The difficulty of containing and collecting agricultural plastic used in open fields poses a unique dilemma. Plastic used in agricultural fields is prone to entering the environment, including the soil, water and air, because it is exposed to the elements and to equipment used in the fields that can cause breakage and degradation (Fig. 1). Small pieces of plastic are both difficult to collect and dispose of, and they are easily stored in the soils or transported to the atmosphere or to open waters, including the ocean. Increased knowledge of the issues and current solutions creates the basis for farmers, researchers, policy makers and others to use in decision making, educational initiatives, technological development, sustainability indices, regulatory decisions, and informing buyer choices.

Advances in agri-technology and management practices have allowed for continued economic gains and more efficient resource utilization within California's agriculture industry and in the Salinas Valley. Plasticulture has played a major role in these gains. Since plastic was first introduced to agriculture in 1948 by EM Emmert as a cheaper greenhouse material, plastic use has expanded to encompass a wide variety of agricultural purposes (Schrader 2000). Plastic mulch is used for weeds, temperature and insect control. Plastic films are used for fumigation, solarization and erosion control. Drip irrigation tape allows for more precise water, fertilizer and nutrient application, often on otherwise non-irrigable land. Hoop houses control temperature and wind for improved fruit quality and yield. Plastic barriers are used on field edges to exclude vertebrate pests (Schrader 2000). These uses have brought about considerable benefits that include an extended growing season (7 – 30 days earlier production), yields increased as much as a fourfold, water savings of up to 80%, reduced weeds and less need for herbicide, control of some soilborne pathogens, and improved produce quality (Schrader 2000).

Figure 1. A) Plastic irrigation tube in the Salinas River. B) Plastic film caught on plant material along streambanks.

The benefit of plastic use to natural resource management and agricultural productivity is undeniable, as is the need to responsibly manage plastic disposal so that it does not degrade on the field or enter Monterey Bay. End-of-useful-life strategies and means for plastic disposal, recycling, replacement and reuses are dynamic and evolving. Means of disposal include landfilling, burning or burying on-site (legally and illegally), incineration to produce energy, recycling, and re-use (Jones 2019). Growing consumer consciousness and conscientiousness has gained a foothold in agricultural marketing with the introduction of cardboard packaging containers for strawberries and finger food vegetables as a replacement for plastic baskets and clamshells. These are more expensive by $0.20 per container; however a class of environmentally concerned customers are willing to pay this premium (Zamora personal communication 2020) and are willing to pay 10% more for strawberries grown on biodegradable mulch (Chen et al. 2019). Innovative drip irrigation manufacturers are creating full circle recycling and reuse. Netafim recycles irrigation tape, tubing and hose into resin that is made into products used in agriculture, landscaping and mining (Netafim 2020). Toro and Delta Plastics have formed an alliance to pick up and recycle used irrigation tubing and greenhouse film, processed into postconsumer resins that are made into trash liners, construction and agricultural products (Toro 2017).

The many uses of plastic in agriculture involve several types of chemistries and additives, each with distinctive characteristics and alternative life cycle strategies (Fig 2). Farm use also affects recyclability as the presence of soil or chemicals adhering to the plastic can increase the processing and transportation costs while reducing the viability of recycling (Levitan 2014). Making purchasing and end of life decisions for the many types of plastics used in agriculture is a difficult and complex undertaking due to the variety of plastics and the changing options for recycling and replacement alternatives of each. Staying abreast of the possibilities is a challenge that growers need help with if we are going to increase the recycling rate, reduce disposal and find competitive alternatives.

Cornell University

AGRICULTURAL PLASTIC PRODUCTS

Differentiating products by resin & color—Characteristics that matter to recyclers

Agricultural Plastic Products	F/R/O	Typical Resin	Usual Color(s)
Bags for wood pellet, peat moss, soil amendments, etc.	F	PE	white, some with print &/or black interior
Bags for feed, grain, birdseed, etc., from small to FIBCs (Flexible Intermediate Bulk Containers) (a.k.a. bulk bags, Super Sacks®)	F or O	Woven PP	white, some printed (note: separate all white from white/black & heavily printed bags)
Bale netting (a.k.a. bale net wrap)	O	PE or PP	translucent green or white or blue
Bale wrap	F	LDPE/LLDPE	white, less commonly green or other colors
Banana bunch bags	F	PE	blue
Biodegradable film	F	PE + additive	various
Boat wrap, blue	F	PE + colorant	blue
Boat wrap, white	F	PE + titanium dioxide	white
Bunker silo cover (a.k.a. silage sheeting) - *with* embedded layer of string webbing for reinforcement	F	LDPE/LLDPE, polyester, some with embedded EVOH layer	white exterior, black interior layer
Bunker silo cover (a.k.a. silage sheeting) - *without* embedded layer of string webbing for reinforcement	F	LDPE/LLDPE, some with embedded EVOH layer	white exterior, black interior layer
Dairy medicinal injectors, *e.g.*, dry cow infusion tubes	R	LDPE barrel, HDPE plunger	white with print
Drainage pipe	R	b	black or white
Drums (typically 55 gallon container for soaps, sanitizers, etc.)	R	HDPE	various
Fumigation and solarization film (a.k.a. soil disinfection film)	F	LDPE/LLDPE	clear or green
Grape cover film (protection from rain)	F	LDPE/LLDPE	clear
Greenhouse, hoophouse, tunnel covers, perforated row covers	F	LDPE/LLDPE	clear or white
Floating row cover (cloth-like material, *e.g.*, Reemay™)	O	Non-woven PP or polyester	white
Horticultural mulch film	F	LDPE/LLDPE	black, less commonly white, clear, or other
IBCs (Intermediate Bulk Containers) (a.k.a. tote, pallet tank)	R	HDPE	translucent milky hue
Irrigation pipe	R	HDPE	black
Irrigation drip tape	O	PE, PVC	black
Irrigation polytube	F	LDPE/LLDPE	white
Maple tubing without fittings (fittings, connectors removed)	O	LDPE	blue or black or clear
Maple tubing, with plastic fittings (metal removed)	O	LDPE, with nylon or PC fittings	blue or black or clear
Nursery plant pots, seedling trays, etc.	R/O	HDPE or PE &/or PP	various
Oxygen/moisture barrier film (*e.g.*, Silostop)	F	EVOH	translucent orange or with yellow-green tint
Pesticide containers (cleaned per ACRC protocols)	R	HDPE	various (see acrecycling.org)
Plastic-lined paper sacks and paper-lined plastic sacks	O	Paper, PE	paper of various colors; plastic typically clear
Silage bags, tuber bags, bulk grain bags	F	LDPE/LLDPE	white exterior, black interior layer
Twine (a.k.a. polytwine, used to tie bales of livestock feed)	O	PP	various
Twine (cordage for tying tomatoes, other horticultural material)	O	PP	various
Water membrane pond liners (a.k.a. geotextiles)	O	PE or PP or EPDM synthetic rubber	black

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Figure 2: Many different types of plastic are used in agriculture and each must be considered individually to determine the best end of life strategy for recycling, disposal or replacement.

Agriculture in Monterey County is vital to the county's fiscal health and to retaining the beauty of the open landscape that appeals to tourists and residents along this awe-inspiring coastal area. In 2018, vegetable, fruit, nursery and field crops grossed $4.26 billion in revenues in Monterey County. The proximity of farms in the agriculturally intensive Central Coast region provides opportunities for economies of scale for plastic suppliers and recyclers that are not feasible in other regions where farms are geographically dispersed (Denton Plastics –personal conversation). This has led to an increased recycling rate for drip tape on the Central Coast as on-farm retrieval is an option offered by full circle suppliers and recyclers leveraging the opportunity of lower travel distances. However, Monterey

County agriculture's recycling rate remains low overall. Not all ag plastic can be recycled and each type of ag plastic must be separated and managed independently (Jordin Simons interview with Encore). The availability of drop off locations as well as labor and time requirements to deal with plastic are barriers to recycling (Levitan and Barrows 2008). Figure 3 displays the decision-making criteria growers might use regarding how to deal with spent plastic, which involves the evaluation of multiple factors including costs, technology, environmental considerations and ease of adoption.

Taking time to make plastic supply and end of life decisions is a challenge for producers, as they face many pressing needs and time demands. It is difficult even for the most diligent of us to pull together sufficient information to make informed decisions for the many types of plastic uses and the many considerations involved in making these decisions. Making information more easily available regarding recycling and alternatives available to growers through suppliers, recyclers, waste management districts and agricultural organizations would aid their decision-making process and ability to make sustainable choices.

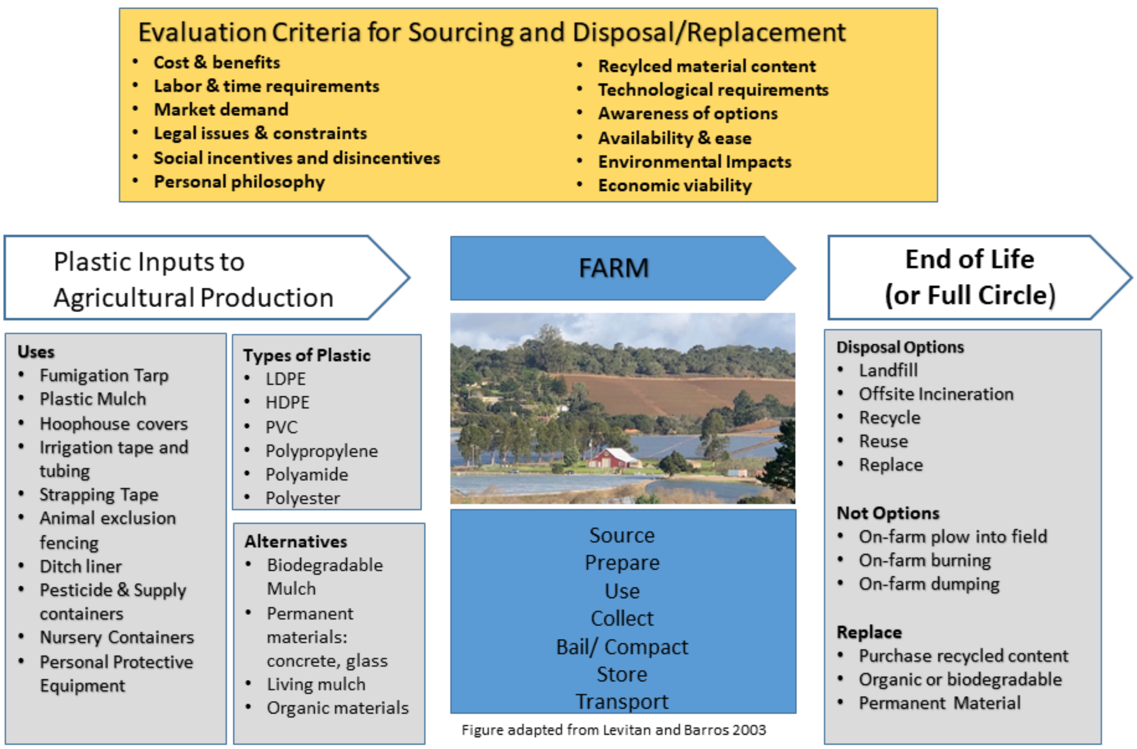


Figure 3: Plastic use and disposal decision-making criteria in agriculture

AMOUNT OF PLASTIC USED IN FOOD CROP PRODUCTION IN MONTEREY COUNTY

Four major types of field plastic (drip tape, plastic mulch, fumigation film and hoop house plastic) used in food crop production in Monterey County were assessed to understand what types of plastic are most at risk for being transported to the ocean. The statistics on plastic use should be viewed in the context of the importance of Monterey County crop production to the supply of fruits and vegetables to the United States. Agriculturally important Salinas Valley supplies 61% of leaf lettuce, 57% of celery, 56% of head lettuce, 48% of broccoli, 38% of spinach, 30% of cauliflower, 28% of strawberries, and 3.6% of wine grapes to the United States (MCFB 2020). Monterey County produces fresh fruit and vegetables encouraged for improving human health. Changes in plastic use should thus be consistent with sustaining agricultural production, crop health and human health.

Calculating plastic use in Monterey County is complicated by the diversity of crop types and geographic settings that affect growing conditions and plastic benefits. More than 50 different crop types are grown commercially in Monterey County and irrigated land covers about 220,000 acres (UCCE). Due to the long growing season offered by the Mediterranean climate, two or three vegetable crops can be grown on the same acreage in a year, sometimes requiring different plastic uses and disposal of single use plastic between crops. This study estimated a total of 10,366 tons per year was used in 2018 in field production in Monterey County agriculture for food crops (Table 2).

This study limited the investigation to plastic that is used in the field for food crop production and did not include plastic needed for packaging, transporting, or incoming supplies such as fertilizer and seed bags, pesticide containers or resin coatings on seeds. Nor did it include cannabis or nursery production. We included drip irrigation tape, plastic mulch, plastic fumigation tarp and hoop houses. Although a drip irrigation system also uses drip tubing and PVC piping, we were only able to quantify the drip tape used in each crop type due to the many different layouts of these systems. The amount of plastic use was quantified in pounds in order to have a common unit of comparison between plastic types. Use estimates incorporated each major crop type reported in the Monterey County Agricultural Commissioner's Crop Report 2018, which includes acreage and crop values. We used University of California Cooperative Extension (UCCE) cost studies, Cal Poly Irrigation and Training Research Center reports and interviews with UCCE specialists, Resource Conservation District technical assistants and product suppliers to complete the information base for plastic estimation. In estimating weight for each field plastic, the study used online information and conservative values for plastic products. Although this study estimated plastic use based on local knowledge and sources, due to the wide array of practices and choices made by individual growers, these estimates should not be viewed or relied on other than as an approximation. Choices regarding type of irrigation, bed size, number of irrigation lines per bed, irrigation tubing width and thickness, choice of mulch color and thickness, along with many other agronomic decisions influence the amount of plastic use. We were not able to include all field plastic in our estimation because we could not find information sources for animal exclusion fencing, plastic lined ditches for erosion control, plastic pots and trays, or baling material. Based on these information sources, the acreage and types of plastic used by crop or crop type is shown in Table 2.

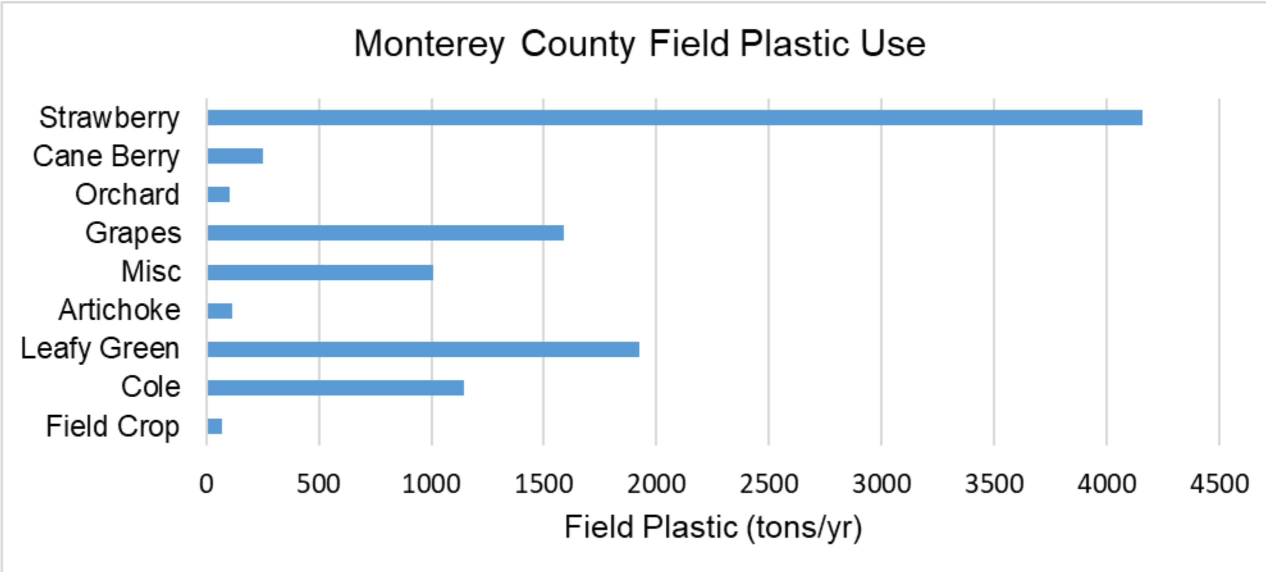
Plastic use can change through time as new products and solutions are tried, new pests require control, and new ways are found to economize resources. Growers also make different agronomic choices. In drip tape plastic estimates, we assumed spring mix, spinach and alfalfa were not drip irrigated because these crops have a short growing season and the plant growth pattern is across the entire field rather than in rows (Cahn pers. communication). Some growers irrigate with sprinklers or flood irrigation on cole crops while others use drip irrigation. The University of California Cooperative Extension (UCCE) irrigation specialist and irrigation suppliers estimated the percent of fields using drip irrigation for particular crop types: broccoli (70%), Brussel sprouts (25%), cabbage (50%), cauliflower (65%), and head lettuce (85%). In our plastic estimates, we utilized these percentages over the acreage of production to arrive at the total field plastic used and the average use by crop.

Table 2: Using UCCE cost studies and personal interviews, we estimated the use of plastic in fields for crop production in Monterey County in 2018 as 20 million pounds.

Crop Type	Planted Acreage 2018	Drip Tape (lbs/year)	Hoop House Plastic (lbs/year)	Mulch and Fumigation tarp (lb/yr)	Total Field Plastic (lb/yr)
Artichoke	5,993	232,941	0	0	232,941
Cane Berry	905	11,104	401,765	85,147	498,016
Cole	82,175	2,286,960	0	0	2,286,960
Field Crop	9,583	142,326	0	0	142,326
Grapes	44,924	3,179,945	0	0	3,179,945
Leafy Green	131,683	3,848,480	0	0	3,848,480
Misc	50,402	1,764,045	197,109	55,685	2,016,839
Orchard	1,938	207,995	0	0	207,995
Strawberry	9,839	517,876	0	7,801,007	8,318,882
TOTAL		**12,191,672**	**598,874**	**7,941,839**	**20,732,384**

Conventionally grown strawberries sometimes use both totally impermeable film (TIF) for fumigation tarp and polyethylene (PE) plastic mulch for weed, temperature and disease control. In other cases, the TIF doubles as a mulch. Currently about 60% of conventional strawberry fields use both film types (Bolda personal communication). Organic strawberry growers use only PE mulch and are required to completely remove it from the field at the end of production to sustain organic certification. In our estimates of PE mulch weight, we assumed use of both TIF and PE mulch for 60% of growers and only the use of TIF for 40%.

Our estimate of the total field plastic use in Monterey County by crop type and on a per acre annual basis by crop type are shown in Figure 4.



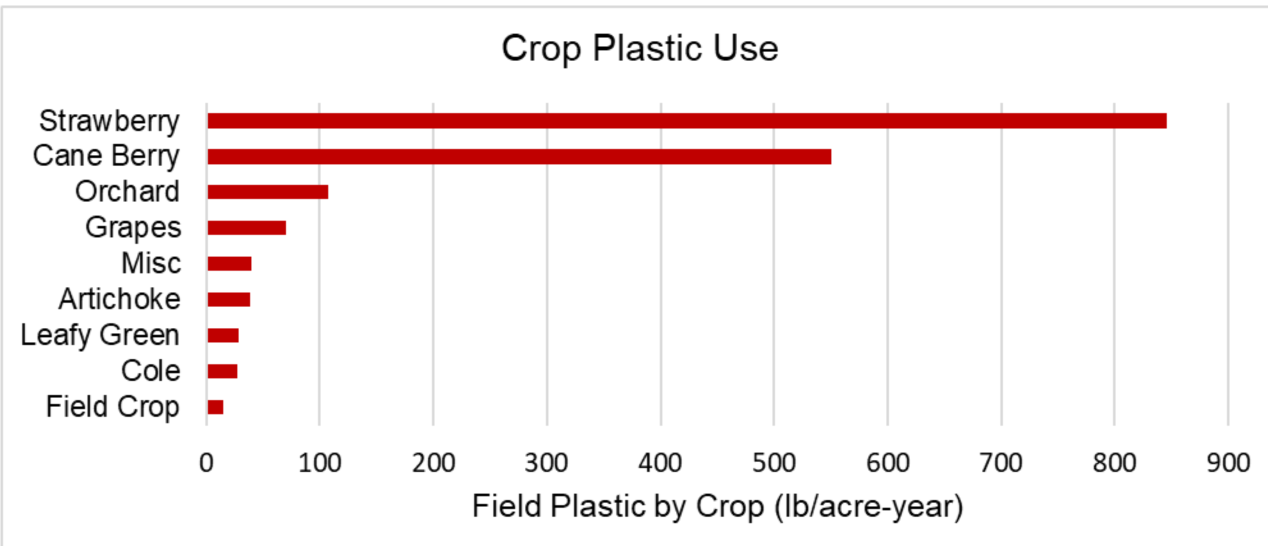


Figure 4: A) We quantified the total amount of field plastic (irrigation tubing, plastic mulch, fumigation tarp and hoop houses) used by crop type for crops grown in Monterey County, based on UCCE cost studies and personal interviews. , B) For each crop type, we estimated the field plastic per acre.

MAJOR PLASTIC USES AND DISPOSAL OPTIONS FOR FOOD CROP PRODUCTION IN MONTEREY COUNTY AGRICULTURE

This study investigated the purpose and use, amount of plastic by weight, and end of life/disposal options related to drip irrigation tape, PE mulch, TIF fumigation tarp and hoop houses for Monterey County field food crop production.

POLYETHYLENE PLASTIC MULCH

USE

In California, PE mulch is used in strawberry production and in the production of high value vegetable crops: tomatoes, melons, squash, peppers and eggplants (Mitchell et al. 2004). Plastic mulch helps maintain thermal conditions near the plant's roots, prevents weed growth, retains moisture, increases the length of the growing season, manages some pests, lowers pesticide use, increases water efficiency and increases yield (Schrader 2000, Johnson 2005, Liu et al 2014). Most mulches are made of high- or low-density polyethylene (HDPE or LDPE) ranging from 7.7 to 20.2 mm in thickness (Mitchell et al. 2004). Mulch is sold in a variety of colors that provide different benefits, with black being the most commonly used in Monterey and Santa Cruz counties (Schrader 2000, Bolda personal communication).

In strawberry production, TIF fumigation tarp used for controlling soil diseases and weeds sometimes doubles as plastic mulch. In these cases, after beds are formed, the TIF is applied and the fumigant is diffused through the irrigation system. This reduces film plastic use by half, as the tarp and mulch are about the same weight. However these two films, PE mulch and TIF, are a different composition and do not have the same disposal or replacement opportunities. A separate section of this paper will describe fumigation tarp.

Incomplete removal from the field is a horticultural issue due to breakage when PE mulch is removed. In an experimental trial, Miles (2019) found that 10% of the PE film plastic remains in the field using common field methods, although this may vary by soil type, length of time in the field, and removal method. Some farms use extreme care when removing PE mulch, utilizing equipment that cuts the mulch in the center or into three strips so that there is less drag and breakage on the tucked edges during removal, as well as employing follow up personnel to remove remaining plastic fragments (Anonymous strawberry producer personal communication). Because polyethylene is extremely resistant to biodegradation due to its high molecular weight and cross-linked chemical structure, these plastic fragments remain in the soil environment for a long time (Gautum et al. 2007). Overtime accumulation of mulch fragments is a source of pollution to the soil and can result in soil health issues including diminished numbers of earthworms, damage to the structure of soil aggregates, reduced soil aeration and lower water permeability (Huerta et al. 2016, Jiang et al. 2017). Other studies have shown microbial biomass is significantly reduced with increasing amounts of film residues, however whether this is directly attributable to the PE plastic residue, accompanying plasticizers or adhered pesticides remains uncertain (Moreno and Moreno 2008, Qi et al. 2020). These soil health changes reduce root growth and overall plant productivity, thus the long-term sustainability of this practice is questionable despite the short-term benefits identified in the introduction (Jiang et al. 2017).

Disadvantages of plastic mulches include cost of removal, degradation of soil health and long-term persistence in the environment (Shogren and Hochmuth 2004).

DISPOSAL

PE mulch is difficult to recycle due to soil and other contaminants. Soil can account for 50-80% of the combined weight, which increases transportation costs and requires removal through intensive separation and cleaning that abrades recycling equipment and causes excess wear during the recycling process (Jones 2018). Because some PE mulches used are co-extruded with a metallic layer which is not recyclable, these must be separated and removed from the recycling stream. Additionally, the adhered soil removal causes a loss of valuable top soil of up to 1010 lbs/acre (Zhang and DeVetter personal communication). Equipment designed to shake or roll soil loose of the film has been developed, but has not gained substantial adoption. Approximately 30-40 million pounds of PE mulch is used and disposed in California annually (Wortman personal communication). Locally the average annual cost of PE mulch removal and transport to waste management facilities is $485-$600 per acre (Bolda et al. 2009).

A number of recyclers have been unsuccessful in attempts to recycle plastic mulch film in California. Community Recycling in Sun Valley, CA invested $10 million in a recycling facility that was operational for less than 2 years (Wortman personal communication). ENO Plastics in Camarillo, CA was launched in 2005 and closed in 2009, shutting operations due to higher than anticipated costs to remove dirt and increased maintenance costs due to equipment wear (Goldstein 2009). Encore Recycling in Salinas opened in 2012 and remains in business but has discontinued recycling mulch film due to contamination and difficulties in developing end use products from the recycled material (Vasquez 2019 personal communication). The cost of recycling PE mulch exceeds the cost of producing virgin PE resin, making it economically infeasible without subsidies from growers, government or some other entity (Vasquez pers. communication).

Currently there are no recycling alternatives for PE plastic mulch in Monterey and Santa Cruz Counties so the only avenue of legal disposal is to a regional waste facility. The Monterey Regional Waste Management District (MRWMD) landfilled 6000 tons of plastic in 2019, half was film plastic (MRWMD personal communication). Burning and burying PE mulch are illegal activities in California and therefore not a disposal option. Offsite incineration is currently not available locally, although an incineration trial by Suwanee American Cement found high BTU value in ag film (Jones 2018). However, due to the dirt content of the film, the operation was not economically viable and was discontinued.

REPLACEMENT ALTERNATIVES

Replacement alternatives to PE plastic mulch include biodegradable mulch (BDM), paper, straw, pine needles and wool. Straw works effectively in some climates for strawberry production and is typically used in climates with cold winters and short summers (Dauguard 2008). Trials of wool paper found that cold soil temperatures caused delays of 3-5 days in flower development and overall lower yields (Daugaard 2008). A matted row system of production does not rely on plastic for weed control and works well in northern climates, however has not gained adoption on California's Central Coast (Guarena and Borne 2008). Trials of organic mulch alternatives such as straw, paper or other materials could be useful for the Central Coast, however these do not hold the heat that brings about earlier and faster plant and fruit growth. The largest advantage of replacement materials to organic growers is lower labor costs through avoiding removal of PE mulch, perhaps offsetting a shorter production period and potentially lower yields.

BDMs have proven equal in performance in terms of the agronomic benefits compared with PE mulch: matching yields, product quality and production timing in pumpkins grown in Tennessee (Velandia et al. 2020). These benefits are also expected in strawberry production, with forecasts that BDM will perform similarly to PE mulch in terms of yield, weed control, reduced use of pesticides, early crop production, and reduced irrigation water (Chi et al. 2019).

BDMs are intended to be plowed into the soil at the end of the crop cycle, where they are designed to fully biodegrade into carbon dioxide, water and cell biomass (Dentzman and Hayes 2019). The development of standards qualifying products as biodegradable are important to prevent false advertising and have been developed to exclude oxodegradable or photodegradable products that do not fully decompose. A number of organizations sets standards for BDM, both national and international, resulting in differences for testing such as in-field decomposition versus higher temperature compost decomposition. The European Committee for Standardization developed an international standard (EN17033) intended to build harmony among these groups. EN17033 specifies BDMs testing in ambient soil and requires 90% conversion of the carbon atoms to CO_2 in 2 years. The standard is not 100% is because some BDM carbon is converted into microbial biomass and additionally there are precision difficulties with testing completeness of degradation (Dentzman and Hayes 2019). Although BDM has been accepted for use in organic agriculture in Europe and Australia, currently no biodegradable plastic mulch product has been certified for use in organic agriculture by the National Organic Standards Board in the United States (USDA NOSB). This is principally because currently manufactured BDMs have not been able to meet the US standards for non-GMO biobased materials.

Per Acre Cost Comparison

	PE Plastic Mulch	Biodegradable Mulch
Mulch Installation		
Machinery	$108.75	$108.75
Material	$405.00	$1,050.00
Installation labor	$240.00	$240.00
End-of season		
Mulch removal	$682.50	$0.00
Mulch disposal	$15.59	$0.00
Mulch tilled into the soil	$0.00	$244.50
Total Cost	**$1,451.84**	**$1,643.25**
Difference in Using Biodegradable Mulch		*$191.41*

Figure 5: Cost Comparison Calculator shows that PE removal costs offset BDM material costs.

Biodegradable mulch and PE mulch are similar in cost if one considers purchase price, labor and equipment. An online calculator developed by the University of Tennessee allows for comparing the costs of the two mulch products (Chen et al. 2018). Inputs to the calculator are labor, equipment and operational costs as well as product specifications. In some cases, a lower cost for BDM may result from labor and disposal costs savings.

Comparison Calculator

Marketers expect demand for BDM to grow globally as consumers increasingly purchase products perceived as eco-friendly solutions to the mounting plastic pollution problems in the soil and the ocean. In a consumer survey, Chen et al. 2019 found that consumers are willing to pay 10% more for strawberries grown on biodegradable mulches.

Despite the positive market, agronomic and environmental potential of BDMs, a number of knowledge gaps and acceptance hurdles remain to gain support and adoption in Central Coast strawberry production. The performance concerns voiced by growers related to local berry types and growing conditions included unknown time requirements for breakdown under local environmental conditions, the long-term impact on soil health, ability of agricultural systems to use current technology and equipment when converting from PE to BDM, disease responses and comparative costs. Although the purchase price of BDM is higher, the overall cost compared with PE mulch is similar because BDM does not have to be removed from the field or transported to a waste management facility (Miles personal communication 2020). Under conventional production where fumigation tarp doubles as mulch (approximately 40% of the time), BDM represents an added cost and is not economically justified. Because BDM is not currently approved for organic production, it could only be used in these systems if it were completely removed and if market advantage would cover the higher costs.

Figure 6. A) Plastic mulch covers 11,000 acres in Monterey County. B) Removal from the field is incomplete leaving fragments behind that accumulate in the soil. C) PE mulch is rolled and stored for disposal. D) Plastic mulch disposal at regional waste management. In Monterey County's MRWMD 5698 tons of plastic film was disposed in 2019.

Fumigation Tarp

USE

Fumigation tarp is used to cover a field when a fumigant is applied to kill pests including weeds, mites, and pathogens. The application of a fumigant requires the use of a film that will contain the fumigant for a period needed to effect the targeted pests. The US EPA requires a buffer zone around the field where a fumigant is applied that is pesticide and condition specific, however must be a minimum of 25 feet around the perimeter of the field (USEPA 2012). California has stricter standards and has larger buffers near schools, of up to ¼ mile (CADPR 2018). The buffer zone is in effect for a specified timeframe, with a 36-48 hour minimum. This buffer zone provides protection to farm workers and bystanders who live near the fields as well as children in schools from health risks. Totally Impervious Films (TIF) and virtually impervious film (VIF) better contain the fumigant and qualify for a reduced buffer zone. TIF allows for a smaller buffer compared with VIF, therefor is the preferred product in Central Coast production. In addition to increasing the field size through allowing a reduced buffer area, TIF also allows for lowering the amount of fumigant use by half (Gao et al. 2014). Because TIF holds fumigant in the soil for a longer period than standard tarp, a longer delay is required before planting, usually about 2 additional weeks.

With the phase out of methyl bromide, the most effective fumigants used in strawberry pest management control of nematodes, pathogens and weed seeds are chloropicrin (sometime combined with metam 1,3-dichloropropene) followed by metam sodium (Bolda et al. 2018). Because these fumigants are less volatile than methyl bromide, they can be applied through the drip irrigation system after the beds are formed. However, sometimes a flat tarp is used to fumigate the entire field rather than fumigating the beds as the edges of the beds and furrows are otherwise not protected from pathogen growth (Fig. 7). In 2018 about 55% of CA strawberry acreage was drip fumigated, however in 2020 this had diminished to only about 40% due to increased disease control provided by flat fumigation (Bolda et al. 2018, Bolda personal communication).

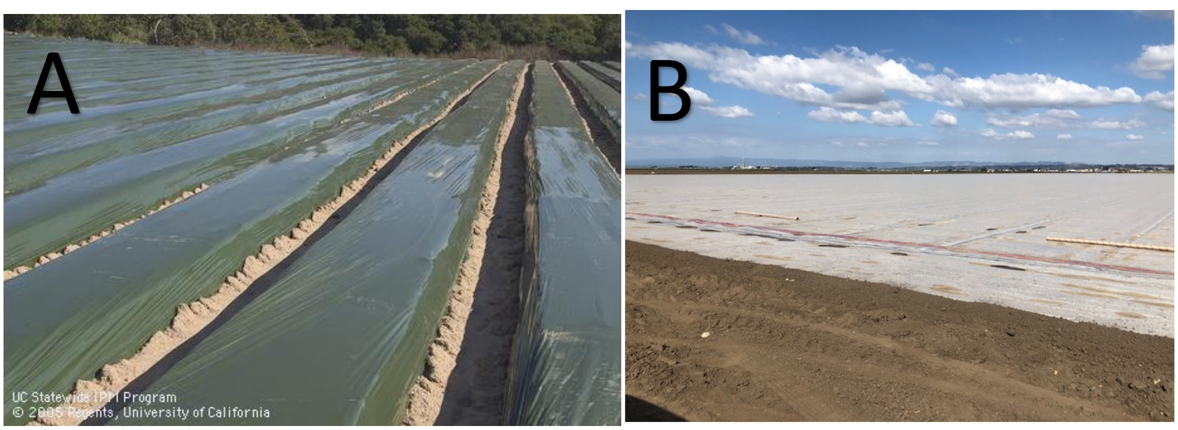


Figure 7. A) Beds are formed and covered with totally impermeable film (TIF) before drip fumigation. Furrows are not fumigated and pathogens can remain in the soil. B) Flat fumigation covers and treats the entire field, however uses twice the plastic because TIF fumigation film is removed and replaced with PE plastic mulch for bed formation. Photo credit: A) Jack Kelly Clark, B) Pam Krone

When a field is flat-fumigated with TIF, then the TIF film is removed and disposed. It is currently not possible to collect it for re-use. Thus when a field is flat fumigated, both TIF and mulch films are used in strawberry production.

DISPOSAL

TIF film is composed of 5-7 layers of extruded plastics that include polyethylene (PE) and Ethyl vinyl alcohol (EVAL) resin and glue, making it virtually impossible to recycle. All TIF is currently disposed of in landfills. Other options such as incineration are not currently available locally, however should be further investigated as an end of life alternative.

ALTERNATIVES

Anaerobic Soil Disinfection (ASD) has been used for pest control of soil borne pathogens, nematodes and weeds in strawberry systems (Shennan et al. 2018). ASD was developed as an alternative to fumigation and is a process that disinfects the soil anaerobically by the addition of carbon and water.   In a 2010 trial, Shennan et al. obtained equal yields compared with methyl bromide in Salinas and 15% lower yields in Watsonville. The ASD did suppress Verticilium dahliea. Many questions remain about scaling up to a full field level, the control of other pathogens and the economics (Shennan et al. 2018).

Hoop Houses

USE

A hoop house or high tunnel is a non-permanent structure made of a metal frame draped with 6 mil thick semi-clear plastic (Fig. 8). On the Central Coast hoop houses are used for cane berry production as well as for starting plants and extending the growing season. In cane berry production, the plastic is reused for an average of 3 years (Bolda at al. 2012). The frame remains in place, and the plastic cover is put up at the start of the season in March. The plastic is removed in late October following harvest. The most common film used on the Central Coast is a PE film that may have additional layers to reduce dust adherence to the film, to prevent breakdown from UV radiation and to increase mechanical strength.

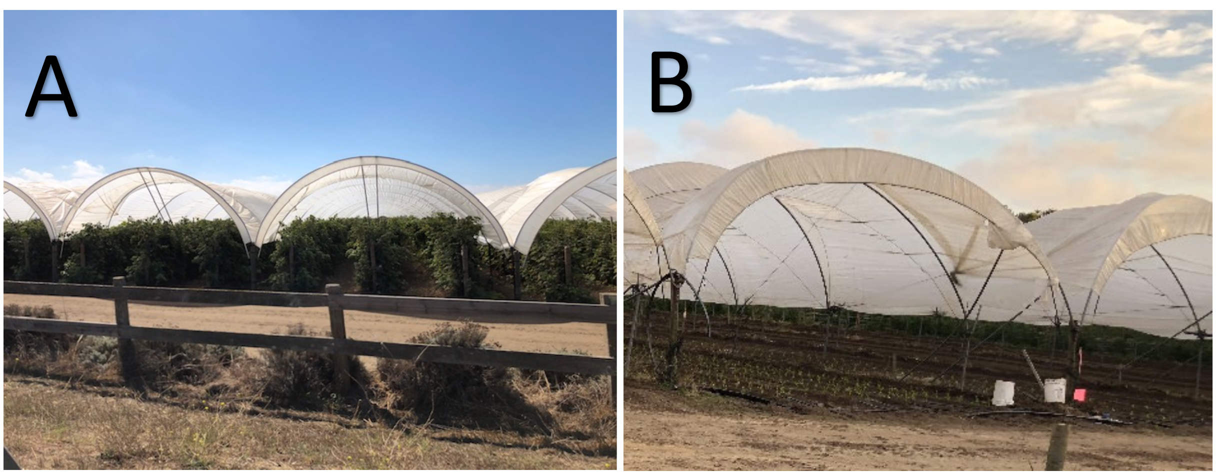


Fig 8. A) Hoop houses are used in cane berry production. B) Hoop houses are used for starting plants and for extending the production season. Photos Pam Krone.

DISPOSAL

Encore Recycling in Salinas recycles hoop house plastic. Their collections manager, Theon Smith, can help schedule pickups: tsmith@revolutionplastics.com

Drip Irrigation Tape

USE

Drip irrigation is cost and water efficient, saving 80% of the water used in sprinkler or flood applications (Schrader 2000). Drip applies water directly to the root zone of a crop, allowing the grower to ideally place nutrients or chemicals and reduce leaching to groundwater (Schrader 2000). Drip irrigation tubing represented the highest field plastic use in Monterey County, with over 12 million lb./yr used on crops. Most crops use drip irrigation in Monterey County with the exception of spring mix, spinach, some root crops, alfalfa and other field crops (Cahn personal communication). In some cases not all growers use drip for a particular crop, such as cole crops. Orchards commonly use micro-irrigation, which is similar to drip irrigation but employs a smaller volume sprinkler head. In the past 5 years single use drip tape was introduced and has been widely accepted because of the labor savings over traditional drip tape. It is a lighter weight tape, and has not dramatically increased plastic use. An added benefit is that many single use drip tape manufactures will recycle the drip tape. Some recycle it into other irrigation products while others have made arrangements with recyclers to pick it up and recycle it into building products or other uses.

DISPOSAL

Drip irrigation tape can be recycled, and there are options available for Salinas and Watsonville growers that include onsite pickup (Fig 9). Netafim will pick up spent drip tape and recycle it. Toro and Revolution plastics have a partnership to pick up used drip tape from growers in California and recycle it at their Encore Recycling Facility in Salinas. Encore washes and recycles the spent tape into plastic resin beads that are sent to Toro of use in irrigation plastic products, creating a closed loop solution. Conditions of pickup can be found through contacting Toro or Netafim.

Figure 9: Pickup for drip tape is available in Santa Cruz and Monterey County:
(https://www.commandpackaging.com/toro).
(https://www.youtube.com/watch?v=rFcudzLmnCg&feature=youtu.be).

We were unable to find an estimate of the number of growers recycling their irrigation tubing. Many growers continue disposing of drip tape at regional waste management facilities either because they fail to meet the requirements of recycling programs or because they do not know about recycling options. One grower suggested that suppliers of drip tape should inform growers of recycling options, stating that when he purchased tape he was not informed that it could be recycled.

ALTERNATIVES

Local options are available for recycling drip tape, no replacement alternatives are currently recommended. Drip tape saves water over other irrigation systems, so we do not recommend discontinuing use. Complete collection from the field is an issue, thus methods to prevent breakage, to collect fragments and to prevent movement off the field should be further developed. Drip tape pick up and conveyance to recycling facilities should be further optimized, as centralized local drop off sites could increase the rate of recycling.

OTHER APPLICATIONS OF FIELD PLASTIC

Other plastic applications include supply packaging, on-site field packaging, as well as irrigation system components like fittings and spray cones. Plastic crates are used for collecting, handling and transporting crops. Plastic tapes are used to help support the aerial parts of the plants and nets to shade the interior of greenhouses. Plastic windbreaks and pest barriers are utilized in areas with intense wind and vertebrate pest damage. Plastic film is used as a ditch liner to prevent erosion (Fig. 10). Polypropylene (PP) is used in several countries especially for bags, strings and twines and nets. Fertilizer sacks and containers are usually stand up pouches made from a combination of plastic such as LDPE, HDPE or polypropylene PP (Briassoulis 2013). Slow release fertilizer pellets are encased in a plastic resin. Plastic sheeting is used for erosion control in ditches. Plastic flower pots, nursery containers and plant tags were previously recycled and reused, however disease transmission has become an issue that has limited container recycling. California law requires that pesticide use registrants recycle rigid pesticide containers through a certified recycling program. In Monterey, a recycling program is available onsite at the MRWMD, made available through the Monterey Ag Commissioner: https://www.cdpr.ca.gov/docs/mill/container_recycling/pest_container.htm.

Figure 10: Plastic lined ditches control erosion but are vulnerable to breakage. Broken pieces can be transported to the ocean with storm water.

REMOVAL, DISPOSAL, RECYCLING

COMPLETE REMOVAL FROM THE FIELD

Complete plastic removal from the field is an issue that could be remediated by methods, equipment and services for retrieving plastic from the field. Improved removal technologies could prevent the loss of top soil during plastic removal, reduce the labor costs, diminish damage to recycling equipment, and prevent the soil and environmental health issues caused by plastic fragmentation. Topsoil loss is significant, up to 1010 lb./acre (Zhang and DeVetter personal communication). Plastic carries soil, water and chemicals, increasing transport and processing costs for recyclers. Labor costs of removal are high, often costing more than the plastic product itself, especially if it is removed by hand. Sophisticated growers consider both supply cost and labor costs in their purchasing decisions. The primary reason single use irrigation tape is rapidly replacing multi-use tape is because of the reduced labor costs during removal. Labor savings more than offset multiple purchases (Netafim 2020). BDM has a higher purchase cost than PE mulch, however it can be tilled into the soil at the end of the crop cycle, thus reducing labor costs. The overall cost of using BDM may be lower in some cases, and comparative costs can be calculated using an online tool developed by the University of Tennessee (Chen et al. 2018). Use of BDM would prevent the loss of valuable topsoil, an ecosystem cost that should be accounted for in purchasing choices (Jones 2018).

Fragmentation of plastic into the environment occurs as the plastic weathers in the field and when it is breaks under tension during the removal processes. These lightweight fragments can be carried by wind and water to local ditches, streams, rivers and eventually the ocean. Growers in Salinas Valley report the use of different methods of field plastic removal. Some mow strawberry plants prior to retrieval of plastic from the field, then use hoe-like equipment to break contact with plastic tucked into the bed edges and wind the plastic into rolls that are stored for transport to waste management. Other growers slit the plastic into three separate strips along the plant lines, then remove the plastic by hand and hire hauling contractors to transport it to the regional waste management facility. Some growers use field labor to remove, roll and transport plastic off site. All strawberry growers interviewed report that they have field labor retrieve fragments from the field following removal of the plastic sheeting. Even with this intensive effort, complete removal is not achieved and some fragments remain. Comparison of the different methods used for removal to evaluate their effectiveness could help growers make removal decisions that would minimize breakage and residual fragments. If dirt and plant material could be more completely removed during retrieval from the field, recyclers would be more likely to profit from recycling PE mulch (Vazques personal communication).

Removing dirt is important because it can add significantly to the weight and the transport cost from the farm to the recycler (doubling the total weight). Dirt can also damage recycling equipment due to it abrasiveness. To prevent these problems, current mechanized removal equipment has been designed to roll, shake or scrape the drip tape or plastic film to remove dirt. Evaluation of different equipment for different applications and soil types could help growers understand what dirt removal equipment could work best for their circumstances (crop, soil, topography, and cost). Andros Engineering specializes in drip tape extraction equipment and retrieval equipment (https://andros-eng.com/) and is designing equipment to remove dirt from mulch (Vasquez personal communication). Some growers use a hauling company to help remove and transport plastic from the field.

Challenges of Plastic Purchasing and Disposal Decisions

An important aspect of the environmental sustainability of single and multiple use plastics is proper disposal to avoid plastic entering the ocean. Pursuing alternatives of recycling, reusing or substituting non-plastic products must be reviewed individually for each plastic use. The challenges of recycling of agricultural material include removing the dirt, maintaining separate piles of different plastic types for retrieval by or delivery to recylcers, and complete removal of all the plastic from of the field. Maintaining separated piles of different plastic types is important to recyclers because different types of plastic are made from different resins and have different polymer chemistry. Even polyethylene, the most common plastic used for drip irrigation tubing and plastic mulch, has different formations such as high density and low density polyethylene, color additives, and sometimes layered film with other chemistries and glues. Mixing plastic types may result in contamination and the inability to use a recycled plastic in the next product. Separate piles enable different plastic to get to the right place in the recycling chain.

Making it easier for growers to recycle is key to increasing the recycling rate. Surveys distributed to CA vegetable, fruit, nursery and grain growers found several ways to increase the convenience of recycling (Fig 11 from Hurley 2008). Growers indicated on farm plastic pick up would greatly encourage recycling (Hurley 2008). Many survey respondents reported that they currently recycle some of their plastic, yet the overwhelming majority do not recycle. The percent of respondents who recycle agricultural plastic included 31% of strawberries growers, 30% of vegetable growers and 38% of orchard growers (Hurley 2008).

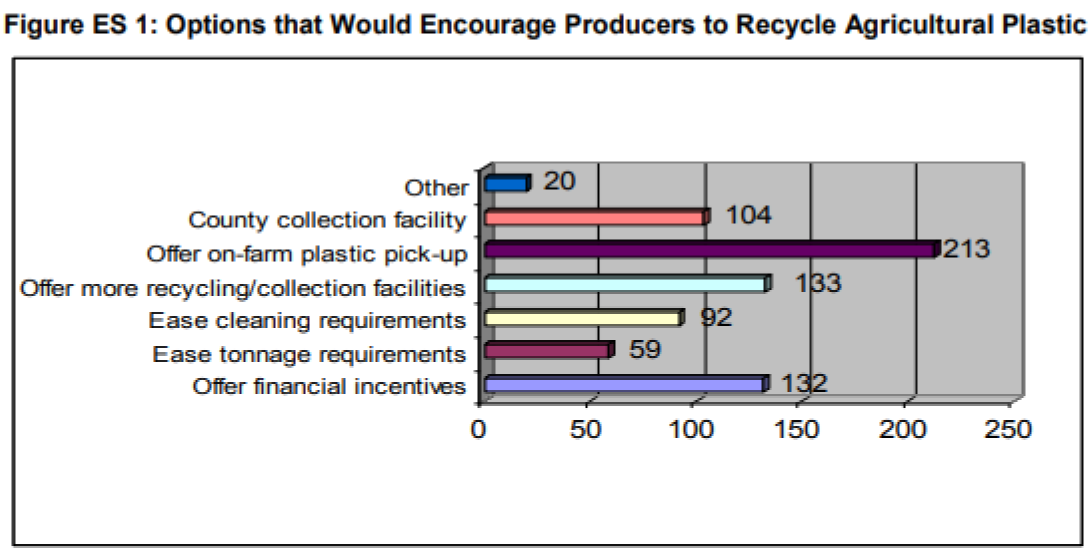


Figure 11: A grower survey conducted by Hurley et al. 2008 for California Integrated Waste Management Board found a number of actions or conditions would increase the rate of agricultural plastic recycling according to respondents. Graphic from Hurley et al. 2008.

SALINAS AGRICULTURAL PLASTIC RECYCLING FACILITY

In 2013, Encore became the first plastic recycling facility in the Salinas Valley able to recycle agricultural plastics (Fig 12). This facility partners with California growers to collect, wash and recycle more that 100 million pounds of plastic per year that would otherwise be landfilled. Encore claims that the agricultural community in the Salinas Valley has adopted the philosophy of ‘recycling with a purpose’. They have partnered with companies such as Dole, Driscoll, Pacific Gold Farms, Ramco, Red Blossom Strawberries, as well as many independent growers. The company has several drop off locations for its partners, one located in Northern and one in Southern Monterey County. The majority of plastics recycled at Encore come from berry hoop houses and drip irrigation tape. They do not recycle fumigation film or plastic mulch (Table 3). Although this facility is leading the way in agricultural recycling efforts, Halimi, the CEO of the company, estimates that only about 25% of Salinas Valley Ag waste is reprocessed (USA Today, 2017).

Table 3. Encore plastic cannot currently accept all types of agricultural plastic, although they are continuously working to expand recycling capability.

Accepted		Not Accepted
Ag bag/ Grain bag	Grape film	Ag bunker cover
Almond cover	Hoop house film	Drip tube
Bin liners	Polytubing - white	Fumigation film
Cotton cover	Solarization film	HDPE netting
Drip tape	Twine - pp	Mulch film
		Pond liner

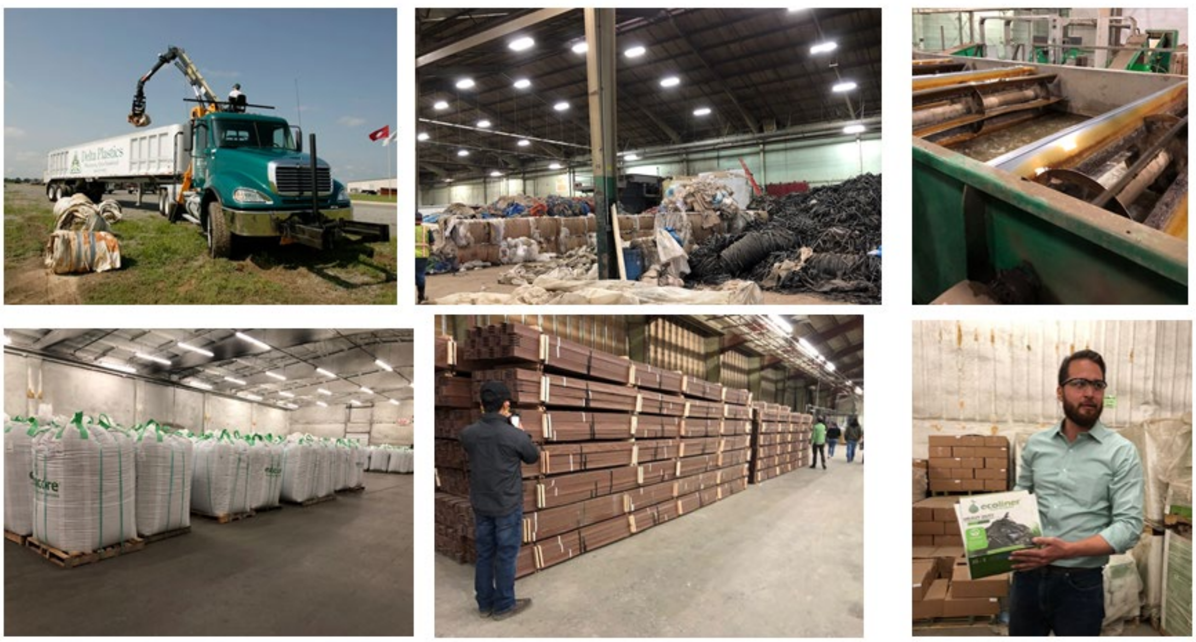


Figure 12: A) Revolution Plastic picks up plastic from field sites and delivers it to their Encore Recycling Center in Salinas. B) Plastic is separated by type into bins. C) Equipment washes and processes the plastic. D) Pellets are bagged for transport for reprocessing into irrigation products. E) Bender board is made onsite and sold for use in landscaping and construction. F) Encore also manufactures bag liners.

PLASTIC DETECTION OF MACRO-PLASTIC ON STREAMBANKS AND MICRO-PLASTIC IN STREAMS IN AGRICULTURALLY DOMINATED LANDSCAPES

In 2018 and 2019, the California Marine Sanctuary Foundation under contract with the Monterey Bay National Marine Sanctuary surveyed stream banks and stream water for plastic that escaped agricultural fields or adjacent urban areas and traveled into riverine systems. The Monterey Bay National Marine Sanctuary is concerned with plastic entering the ocean and recommends the best strategy to prevent plastic ocean pollution is through containment at the source, rather than removal from the ocean. Prevention of plastic movement from urban areas to the ocean will occur as the California Trash Amendment is implemented. California's Trash Amendment was adopted by the State Water Quality Control Board in 2015, with provisions that require the implementation of full capture systems or equally effective alternatives, with full compliance by 2030 (CWB 2015). However, trash amendment regulations do not pertain to agriculture. In order to determine whether plastic entry to the ocean from agriculture may be a problem for Monterey Bay, bank surveys were conducted to characterize the types of trash found on streambanks. Additionally, microplastic (MP) monitoring in streams was undertaken to discover whether plastic particles smaller than 5 mm are present in water that flows through agriculturally dominated landscapes and therefore may have its origin in agricultural uses.

SITES

We sampled at 10 sites (1 river, 1 slough, 4 creeks and 3 ditches) in agriculturally dominated landscapes in Monterey County (Table 4; Fig's. 13 and 14).

Table 4: Ten sampling locations for bank surveys and microplastic monitoring were chosen in agriculturally dominated areas, as close as practical to agricultural Cooperative Monitoring Program sites.

SITE ID	Site Description	Latitude	Longitude	Nearest Cooperative Monitoring Site	Date of Bank Survey	Date of MP Monitoring
309MER	Merrit Ditch upstream from Tembladero Slough confluence at Highway 183	36.752	-121.742	same	12/02/18	09/07/18
309NAT	Natividad Creek near East Blanco	36.702	-121.549	downstream 300 m from 309NAD		01/19/18
309SRL	Santa Rita Creek at Living Water Church	36.730	-121.642	upstream of development from 309RTA	02/10/19	02/10/19
309GAB	Gabilan Creek at East Boronda Road	36.715	-121.617	same	02/24/19	02/24/19
309ALG	Reclamation Canal at La Guardia	36.657	-121.614	same	04/04/19	04/04/19
309QUA	Quail Creek at Potter Road	36.611	-121.549	same	03/09/19	03/09/19
309CRR	Chualar Creek, near Foletta at RR tracks	36.564	-121.514	same	03/18/19	03/18/19
309ADT	Ag Ditch at Trafton	36.872	-121.784	none	03/22/19	03/22/19
309TDW	Tembladero Slough at Molera Road	36.772	-121.787	upstream 200 m from 309OLD	04/14/19	04/14/19
309SAL	Salinas River at Davis Road	36.677	-121.744	downstream 9400 m from 309SSP	06/18/19	

To the extent possible, we monitored the same sites selected for monitoring by Central Coast Agriculture's Cooperative Water Quality Monitoring Program (CMP). In some cases, we were not able to access CMP sites because they were located on or accessed via private property. In these cases, we chose an accessible site as close as feasible using the criteria of public property, nearby parking and safe stream entry. At most sites, we conducted both bank trash surveys and MP water sampling. However, time constraints prevented us from conducting a bank survey at Natividad Creek, and the MP sample at Salinas River was not analyzed.

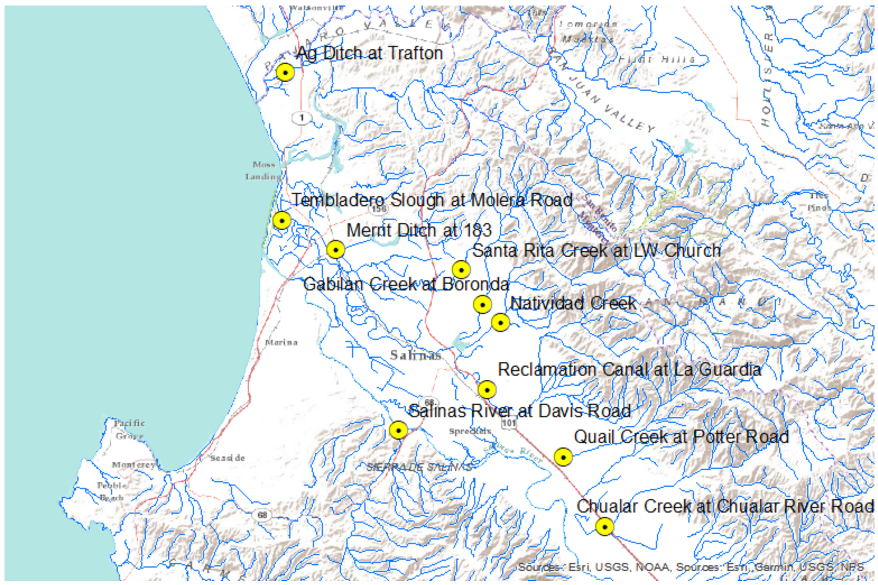


Figure 13: Ten sampling sites for agricultural plastic were chosen near agricultural Cooperative Monitoring Sites. We conducted bank trash surveys on 9 sites and microplastic collection in surface waters at 9 sites.

Figure 14: Site photos of streams sampled for bank trash and microplastic particles.

Bank Trash Surveys

METHODS

We performed bank trash surveys at a total of 9 sites, spending an average of 21 minutes per site. We sampled each creek or slough at the monitoring site from the water's edge to the top of the bank and recorded this as our width dimension. If the bank was too wide (> 20 ft.), we chose a shorter distance. We sampled within a rectangle, choosing a dimension that allowed us to collect trash without going around a curve or entering a very steep area. We placed stakes at each corner of the sampling rectangle to demarcate the bank sampling area. Sampling areas varied between 9.6 m^2 and 255 m^2. We followed a modified NOAA protocol from the Marine Debris Shoreline Survey Field Guide (Opfer et al. 2012), using the categories identified in the protocol for differentiating and counting trash types. As we collected and identified trash, we differentiated pieces by type: plastic (urban and agricultural), glass, rubber, metal, paper and lumber, and cloth. Each trash type was divided into categories per NOAA protocol and trash pieces were counted and noted by category during bank surveys. We added to this list to quantify and distinguish agricultural from urban trash. The additional agricultural categories were drip irrigation tape or tubing, strapping tape, agricultural hard plastic, produce packaging, plastic mulch (green or black film), hairnet, gloves and miscellaneous. Because mulch is a film fragment, any green or black fragments we provisionally identified as agricultural in origin and any white, clear or other colored film fragments we identified as urban. This distinction is imperfect as there are clear and white agricultural films. We collected the urban and agricultural plastic into two separate bags and recorded the number of pieces of each category of trash as we collected them. Items that were too large to remove, we left in place. We recorded the amount of time required to remove visible trash from the rectangular sampling area. All information identified in the NOAA protocol was entered onto field data sheets and later transferred into an excel sheet. We transported the trash back to the lab where we disposed of the urban trash and cleaned and photographed the agricultural trash. Because of the difficulty of completely removing mud from the plastic, we did not weigh the collected trash plastic.

RESULTS AND DISCUSSION

As we collected and identified trash, we differentiated pieces by type: plastic (urban and agricultural), glass, rubber, metal, paper and lumber, and cloth. Each trash type was divided into categories per NOAA protocol and trash pieces were counted and noted by category during bank surveys. Plastic was by far the most common type of trash collected, with the combined urban and ag plastic collected at 24 times the density in pieces per unit area compared with any other type of trash (Table 5). A total of 453 and 516 pieces of urban and agricultural plastic respectively were collected at all locations, representing an average density of 2.45 and 2.33 # pieces/m^2. Urban plastic may be a misnomer, as the origin of the plastic is unknown. What we characterized as urban plastic included personal use plastic items: food wrappers, cups, beverage bottles, cigarette butts, six pack rings, bags and rope. These items could have originated from an urban area or from an agricultural field where people were eating meals, drinking sodas, or engaged in other activities involving plastic use. We also characterized unknown plastic fragments (hard plastic, foam and white or clear film) as urban in origin, although their small size made identifying their use or probable source impossible. These unknown fragments constituted 287 out of 453 plastic pieces categorized as urban (63%).

The Gabilan Creek site in particular is located on the edge of an urban-agricultural interface. It is immediately downstream of agricultural fields and adjacent to a high school and housing area. Gabilan

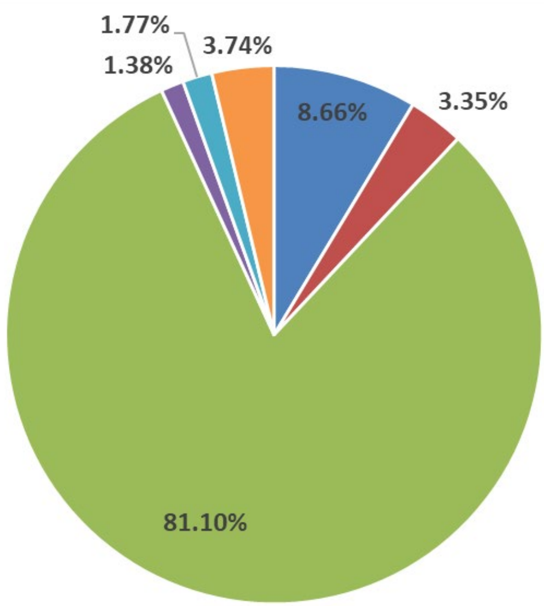
Creek was the site most notably influenced by urban trash (9.07 # pieces/ m^2). Urban plastic found at this site was composed primarily of food wrappers (37 pieces), clear or white film fragments (81), cups (11) and foam fragments (11). It also had agricultural trash: strapping tape (1), drip tape (3), film fragments (55), gloves (4) and broken PVC pieces (5). The Quail Creek bank had the second highest density of plastic identified as urban (6.63 pieces/m^2). This location is in an agricultural area and is not adjacent to or downstream of any urban area or busy street. This urban plastic was predominated by film fragments that were clear or white in color (68 out of 72 pieces of urban plastic trash; 94%). Our characterization of these films as urban is likely incorrect, especially considering the number of hoop houses or greenhouses upstream of the monitoring site, constructed of white and clear plastic. Nurseries and packaging houses also exist upstream of the site in the Quail Creek watershed and may contribute to the plastic pollution. Other sites also contained plastic that could have originated from both urban and agricultural sources (Table 5, Fig. 16).

Table 5: Types of trash collected at each site. Plastic is clearly the dominant litter found on creek, ditch and slough banks monitored in Monterey County agricultural areas.

Site ID	Urban Plastic (pieces/m^2)	Ag Plastic (pieces/m^2)	Metal (pieces/m^2)	Glass (pieces/m^2)	Rubber (pieces/m^2)	Lumber & paper (pieces/m^2)	Cloth (pieces/m^2)
309MER	0.21	0.15	0.03	0.04	0.00	0.06	0.01
309SRL	0.35	2.98	0.00	0.00	0.00	0.00	0.02
309GAB	9.07	3.65	0.11	0.05	0.00	0.00	0.00
309QUA	6.63	9.21	0.16	0.08	0.00	0.00	0.00
309ADT	0.52	1.15	0.00	0.31	0.10	0.00	0.00
309CRR	0.93	1.11	0.09	0.23	0.00	0.09	0.00
309ALG	0.30	1.87	0.00	0.00	0.00	0.00	0.00
309TDW	3.08	0.83	0.00	0.00	0.12	0.21	0.00
309SAL	0.96	0.06	0.00	0.06	0.00	0.00	0.00
AVERAGE	**2.45**	**2.33**	**0.04**	**0.09**	**0.03**	**0.04**	**0.00**

The average density of agricultural plastic collected at the 9 sites was 2.33 pieces/m^2 with variation in density between 0.06 pieces/m^2 on the bank of the Salinas River (309SAL) at Davis Road and 9.21 pieces/m^2 on Quail Creek (309QUA) at Potter Road. The majority of agricultural bank plastic was film fragments, presumably from use as plastic mulch or fumigation tarp, varying in size from 0.2 by 0.2 cm to 5 by 5 cm. A total of 412 plastic film fragments were collected, comprising 82% of the agricultural plastic pieces found. At all sites except Tembladero Slough (309TDW) and Salinas River (309SAL), plastic film fragments were the predominant category of ag plastic found on the bank. On Santa Rita Creek (309SRL) and the Reclamation Canal (309ALG), ag film fragments made up >95% of the agricultural plastic pieces collected in the transect. If we had included white and clear film fragments in our count of ag plastic, this would have added 223 film fragments and increased the density by 54%. Monterey farmland covered by film for crop production in 2018 amounted to 11,000 acres. Although more irrigation tape is used than film (by weight), film tends to fragment and break during removal, and it is light-weight and easily transported by wind and water. Coverage of large acreage, fragmentation and transportability explain its high density on stream banks in agricultural areas (Fig. 15, Fig. 16).

Figure 15: Examples of agricultural plastic collected from banks of water bodies in Monterey County: A) Tembladero Slough, B) Quail Creek, C) Ag Ditch at Trafton , D) Santa Rita Creek, E) Gabilan Creek, F) produce packaging, G) personal protective equipment.



Ag Plastic Category	Average Ag Plastic Particles (#/m^2)
Strapping tape	0.28
Drip tape/Irrigation Tubing	0.07
Plastic Mulch	1.73
Produce Packaging	0.03
Personal Protective Equipment	0.05
Thick plastic fragment	0.04

Figure 16: Percent of agricultural plastic by category shows the two most commonly found on stream banks were plastic mulch and strapping tape.

Strapping tape was the second most common category of agricultural plastic found on streambanks, comprising 8.7% of the pieces found at an average density of 0.28 pieces/m^2. Strapping tape was found in multiple colors including blue, green, white and red and varied in size from 1 cm by 5 cm to 1 cm by 365 cm. The frequency and number of fragments of strapping tape found on streambanks was unanticipated as this tape is primarily used for transport of incoming supplies and outgoing cartons to hold boxes together as a unit on pallets. Because strapping tape was encountered as a long woven segment (0.1-1.5 m), had we measured weight, it is possible that its contribution to plastic pollution on stream banks may have been greater than that of mulch film. Strapping tape was found at all 9 sites, with the highest density at Quail Creek (0.98 pieces/m2) and the lowest at Santa Rita Creek (0.02 pieces/m2). Strapping tape is lightweight and thin, thus easily transported by wind or water. Because it can expand to a large volume when it unravels, we presume there may not be a convenient on-field disposal system for removing strapping tape. Perhaps this lack of ease of disposal could be a reason for its pervasive presence on all stream banks.

The Salinas River bank had the lowest agricultural plastic density of all the sites sampled (0.06 pieces/m^2), despite being a large river downstream of, and adjacent to, an agriculturally dense area. One reason for this lower density could include the large riparian buffer (140 m) between the agricultural fields and the river, perhaps capturing the plastic and preventing its conveyance to the river. As the largest water body sampled, it is also likely that waste on the bank may have been cleared and trash transported downstream by water during peak storm flows, as our sampling event followed California's wet season. The three sites with the highest amount of agricultural plastic on the banks were Quail Creek (9.21 pieces/ m^2), Gabilan Creek (3.65 pieces/m^2) and Santa Rita Creek (2.98 pieces/ m^2). These watersheds are located north and east of Salinas in hilly areas with intensive agricultural production and seasonal creek flows. We sampled these creeks following storm events, where receding flows likely left plastic on the stream banks. These creeks also have bare or sparse vegetation, thus plastic is more easily conveyed to the bank and water (Fig 17).

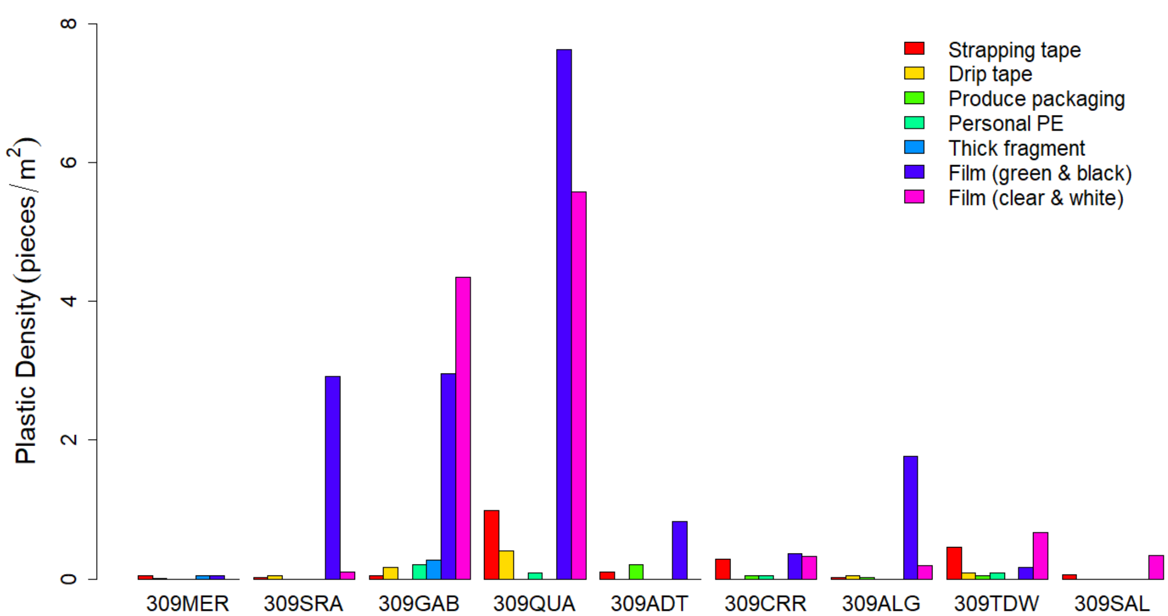


Figure 17: Film fragments were the dominant agricultural plastic found at monitoring locations on stream banks. Although white and clear film fragments are included in this graphic, they were not counted as agricultural plastic. They may originate from agricultural films such as hoop houses or urban films such as wrappers.

MICROPLASTIC MONITORING

SAMPLE COLLECTION METHODS

We collected MP samples from water at 9 sites in 2018 and 2019 (Table 4). We collected duplicate samples at 1 site and field blanks at 2 sites. At each site, we waded into the waterbody with a neuston net (500 um mesh) and collected a sample for a period of 10 to 25 minutes, holding the net perpendicular to the direction of water flow and allowing the net to trail downstream.

We measured the size of the net opening immersed in the water, as some waterbodies were not deep enough to immerse the net completely. In cases where water depth was sufficient, we immersed the net allowing the top to barely graze the water surface in order to collect any floating plastic. At the beginning of the sampling period, we measured water flow rate (m/sec) at the center of the net using a flow tracker (Sontek FlowTracker 6054-60211-B), averaging calculations from two flow rate measurements. We multiplied flow rate by the area of the net opening to calculate the volume of water sampled. On two waterbodies (309ALG and 309MER) the flow rate was < 0.01 m/sec, insufficient to collect a sample, so we waded upstream holding the net in front of us in order to capture a sample. We measured the distance travelled and divided by the travel time as a proxy for flow rate. At the completion of each sampling period, we removed the net from the water and rinsed the sides into the base net container. We transported this container to the Chemistry Lab at CSUMB for further analysis.

Figure 18. A) Riley Ransom and Yulia Loshkareva preparing to sample microplastic on the Salinas River, with the net submerged to the top of the net opening. B) Riley Ransom collecting a sample at Quail Creek, holding the net in place so that it barely touches the bottom of the creek. C) Jordin Simmons walking upstream holding a net in front of her, collecting a sample at Merritt Ditch, during no-flow conditions.

LAB ANALYSIS METHODS

We analyzed the samples collected from waterbodies for MPs using a protocol modified from the NOAA Marine Debris Program (Masura et al. 2015). In brief, upon returning from waterbody sampling, we poured the sample through stacked stainless steel sieves of 4.75 mm and 0.33 mm mesh. We counted and recorded macro-plastic from the 4.75 mm sieve. We transferred the contents of the 0.33 mm sieve into a beaker, rinsing the sieve to achieve complete removal. Then we dried the sample in an oven at 80 °C for 24-48 hours. Organic matter present in the sample was oxidized using a mixture of aqueous 0.05 M Fe(II) Sulfate ($FeSO_4$) and hydrogen peroxide (H_2O_2) heated to a temperature of 75 °C until no organic matter was visible, and then cooled for 10 minutes. When a substantial quantity of sediment was in the sample, we used density separation with an NaCl saturated solution to float the plastic to the top, stirring and repeating several times. Only one sample required this step. When there was insubstantial sediment in the sample, we skipped the density separation step. Then we filtered the sample through fiberglass filter paper and allowed the sample to dry. In some cases, two pieces of filter paper were needed if the filtrate was unusually dense. We used empty filter paper containers and CD cases for storage, and found static attraction of plastic was an issue. We suggest use of static dissipative plastic containers for sample storage.

Each filter paper was divided into four quadrants and two people separately viewed the contents under a dissecting microscope, counting and measuring each MP particle. We categorized MP by color, size and type. The five types were film, fragment, fiber, pellet and foam. Size categories were <2 mm and > 2 mm. Colors were black, green, blue, red, white and clear. For each sample, the count for each category was averaged to combine the observations of the two people engaged in microscopic evaluation. We did not have access to analytical equipment such as Fourier Transformed Infrared Spectroscopy (FTIR) or Raman spectroscopy, so we saved samples for potential future analysis. To differentiate plastic from other materials we used a variety of techniques. If the particle was hard or brittle when poked with forceps, we assumed it was a rock fragment. If the fiber did not distort when touched with a hot needle, we assumed it was cotton. If the particle appeared to be a seed or plant stem, it was coded as such.

We found MPs in our field and lab blanks, at consistently low numbers. The field blanks at 309ALG and 309SAL had a total of 6.5 and 16 MPs respectively, predominated by fibers that accounted for 5 (77%) and 14.5 (90%) MPs respectively. The MPs in the field blank at 309ALG was low relative to the collected sample, only 2%. Unfortunately, the collected sample at 309SAL was not analyzed so comparison is not possible for this site. The contamination of field blanks could have come from clothing worn by field technicians or could have been carried by air into the sample. The lab blank had 1.5 MPs, likely from the same sources.

DISCUSSION AND RESULTS

We collected a total of 1177 MPs from 9 (plus 1 repeated) agricultural sites. These comprised 370 film MPs, 185 fragment MPs), 287 fiber MPs, 332 pellet MPs, and 4 foam MPs. The MP type with the highest count was film (370 particles); however if we consider the volume of water sampled, pellets represented the most highly concentrated MP (5.46 particles/m3). Slow release fertilizer pellet MPs identified at the Reclamation Canal (309ALG) had an inordinate influence on average pellet concentration (Fig. 19). Although pellet MPs were found at 8 of the 9 sites, the relative proportion was much lower at all other sites. Based on the average concentration across all sites, pellets represented 53% of the MP concentration. If we remove the pellet MPs found at 309ALG as an outlier, we observed similar contributions to plastic pollution come from three MP types: films (1.77 particles/m3), fibers (1.25 particles/m3), and fragments (1.78 particles/m3). Thus, MP plastic pollution is coming from multiple sources, and its reduction will require more than a single solution.

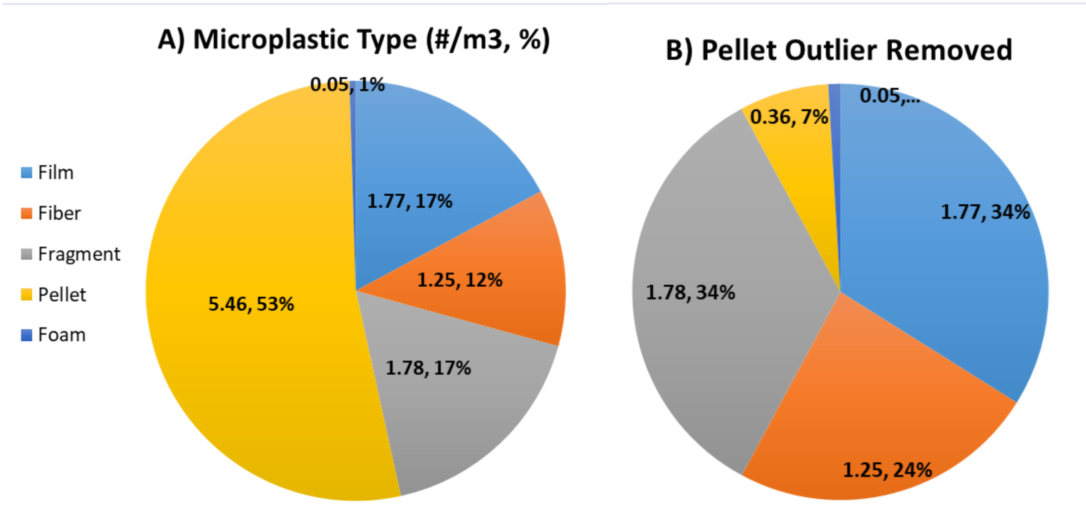


Figure 19: MPs collected from 9 Monterey County waterbodies show a similar density of film, fiber and fragments, if 286 fertilizer pellets found at 309ALG on 4/4/19 are excluded from the sample data. Leaving the pellets as part of the count shows them as the predominant MP pollutant representing 53% of MPs.

All MP pellets in the agricultural sites were from slow release fertilizers, as we did not encounter nurdle pellets, a common ocean pollutant (Fidra 2019). Slow release fertilizer pellets have a resin coating around the outside to delay the rate of release of the fertilizer over the growing period of the crop. The resin surrounding the pellets is composed of polymers such as polysulfone, polyacylonitrile or cellulose acetate that do not degrade (Jaroseiwicz and Tomaszewska 2003, GESAMP 2016). We found both intact pellets including the fertilizer and empty rounded shells, the remains of the coating. Slow release fertilizers can thus be both a plastic and nutrient pollutant when they enter waterbodies from fields. Intact pellets also represent a loss to the farmer if the pellet enters the water stream before the fertilizer is fully released to the intended crop. The plastic coating provides increased buoyancy as well as resistance to dissolution of the pellet in water. The efficacy of slow release fertilizers should be reviewed in light of their tendency to travel off the field and not deliver nutrients as intended.

Each waterbody had its own MP signature (Table 5 and Figure 20). For example, Merritt Ditch (309MER) had more fragments (57 out of 60; 95%) than any other MP type. Santa Rita Creek (309SRL) had a high amount of MP film (133 out of 255.5; 52%) compared with other types, and the Reclamation Canal (309ALG) had a high pellet count (286.5 out of 337.5; 85%). Above the monitoring location on Santa Rita Creek, hillside strawberry production on steep slopes could contribute to erosion of plastic mulch into the Creek during storm events and could explain the high film MP count. We sampled this site following 0.87 inches of rainfall within the prior 48-hour period. On Quail Creek, fibers from the clothing of people working in greenhouses and the packing facilities may have contributed to the relatively high fiber MPs at this site (79.5 out of 140.5; 80%). The high pellet count from slow release fertilizers at the Reclamation Canal site may have coincided with fertilization applications at one or more field operations. This site condition is listed as “very poor” on the Central Coast Ambient Monitoring Program’s (CCAMP) website for Nitrate as N, with a mean concentration of 21.9 mg/L. Preventing fertilizer from entering the Reclamation Canal is important to environmental health as well as regulatory compliance. These differences between waterbodies point to the need for efforts to contain plastic and prevent entry to the environment from multiple agricultural sources including fertilizer pellets, fabric, film and broken fragments.

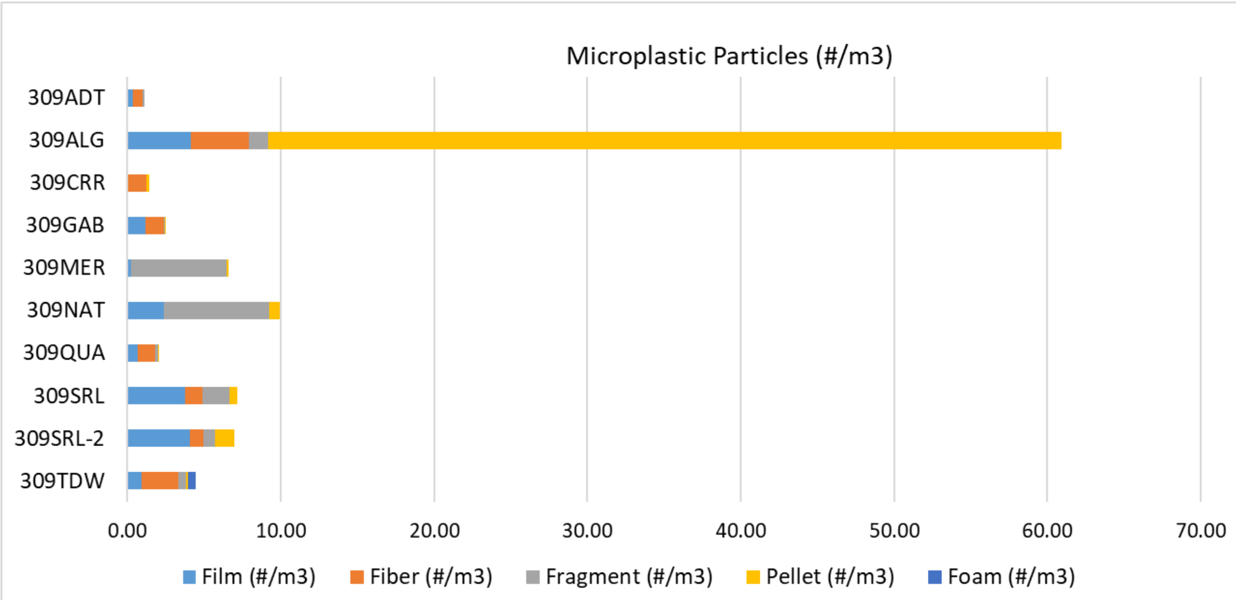


Figure 20: The type of MP content differed between waterbodies, with pellets predominating in 309ALG, fragments in 309MER and 309NAT, film in 309SRL, and fiber in 309TDW and 309CRR.

Table 5: Microplastic particles were identified by type and counted under the dissecting microscope by two technicians, whose results were averaged. The volume of water filtered through the net during collection was calculated in order to estimate MP particle concentration in the waterbody.

Site	Water Volume (m^3)	FILM particles (#)	FILM concentration (#/m^3)	FIBER particles (#)	FIBER concentration (#/m^3)	FRAGMENT particles (#)	FRAGMENT concentration (#/m^3)	PELLET particles (#)	PELLET concentration (#/m^3)	FOAM particles (#)	FOAM concentration (#/m^3)
309ADT	34.58	12	0.35	23.5	0.68	4	0.12	0	0.00	0	0.00
309ALG	5.54	23	4.15	21	3.79	7	1.26	286.5	51.71	0	0.00
309CRR	5.55	0	0.00	7	1.26	0	0.00	1	0.18	0	0.00
309GAB	69.08	80	1.16	86	1.24	2.5	0.04	3.5	0.05	0	0.00
309MER	9.1	2	0.22	0	0.00	57	6.26	1	0.11	0	0.00
309NAT	2.92	7	2.40	0	0.00	20	6.85	2	0.68	0	0.00
309QUA	69.83	45.5	0.65	79.5	1.14	15	0.21	0.5	0.01	0	0.00
309SRL	35.48	133	3.75	40	1.13	64	1.80	18.5	0.52	0	0.00
309SRL-2	14.89	61	4.10	12.5	0.84	12	0.81	18	1.21	0	0.00
309TDW	7.1	6.5	0.92	17	2.39	3.5	0.49	1	0.14	3.5	0.49
Average		370	1.77	286.5	1.25	185	1.78	332	5.46	3.5	0.05

COMPARISON OF MICROPLASTIC DENSITY WITH OTHER STUDIES

In a review of studies of different areas in the United States, in some cases the receiving water body had lower plastic density than the contributing water bodies and in other cases the opposite was true (Table 6). The MP density found during this study in flowing waterbodies in agricultural areas of Monterey County during our study (1.1 – 60.9 # particles/m3) was the same order of magnitude as the MP density found by Choy et al. 2019 in Monterey Bay at multiple depths (2.9 – 15 # particles/ m^3). This is in contrast to SFEI's findings that urban tributaries to SF Bay had lower plastic density (0.001 to 0.03 particles/ m^3) than the ocean water outside SF Bay (0.3-65 particles/ m^3; Sutton et al. 2019). At the other extreme, tributaries to the Great Lakes had a higher concentration of plastic (32 # particles/m^3) than did the receiving water in the Great Lakes (0.27 # particles/ m^3; Erikson 2013, Baldwin et al. 2016). In all cases, the continued delivery of MP particles from streams to the ocean is a source of MPs to the ocean that may contribute to increased ocean plastic concentration through time, depending on the rates of plastic weathering and degradation in the ocean environment, rates that are currently unknown (GESAMP 2016).

Table 6: Different studies of microplastic concentrations show a variation in particle density. Note that receiving water bodies (lakes and ocean) can have higher or lower concentrations than contributing water bodies (streams, sloughs, ditches and storm drains).

Location	Waterbody Type	Density (# particles/m^3)	Study
Global ocean surface water (mean)	Ocean	0.96	Shim et al. 2018
SF Bay	Ocean	0.3- 65	SFEI
Marine Sanctuaries	Ocean	0 - 0.5	SFEI
Urban Tributaries to SF Bay	Stream	0.001-0.03	5 Gyres/SFEI
Los Angeles River	Stream	418	Moore et al 2011
Monterey Bay ocean surface	Ocean	2.9	Choy et al. 2019
Monterey Bay ocean surface	Ocean	0.26-3.21	Kashiwabara et al. 2020
Monterey Bay 200 meters deep	Ocean	15	Choy et al. 2019
Merrit Ditch	Stream	4.4	This study
Natividad Creek	Stream	9.9	This study
Santa Rita Creek	Stream	7.2	This study
Gabilan Creek	Stream	2.5	This study
Chualar Creek	Stream	1.4	This study
Quail Creek	Stream	2.0	This study
Ag Ditch at Trafton	Ditch	1.1	This study
Reclamation Canal	Ditch	60.9	This study
Tembladero Slough	Slough	4.4	This study
Quail Creek	Stream	4	CSUMB 660 class
Santa Rita Creek	Stream	18.9	CSUMB 660 class
Gabilan Creek	Stream	0	CSUMB 660 class
Urban Outlet 1 Pacific Grove	Storm Drain	12.6	CSUMB 660 class
Urban Outlet 2 Pacific Grove	Storm Drain	34.8	CSUMB 660 class
Urban Outlet Monterey	Storm Drain	2.1	CSUMB 660 class
Great Lakes	Lake	0.27	Erikson 2013
Great Lakes Tributaries	Stream	32	Baldwin et al. 2016

A CSUMB 660 class sampled three of the same agricultural streams in 2019 that we had sampled previously and added sites at three urban outlets to the Pacific Ocean in Monterey County. Sampling took place following rain events in December 2019 (CSUMB 660 2019). CSUMB found twice the plastic concentration at two agricultural streams compared with our results. This increase is not necessarily an indication of higher plastic content in the year between samples, but could be due to normal variability, seasonality, timing of sampling following rain events, or other factors. The third stream CSUMB sampled for less than a minute, and no particles were found. CSUMB 660 observed a higher concentration of plastic MPs in urban outlets (average of 16.5 #/m3) compared with agricultural streams (average 7.6 # particles/m3). However, when they computed the load of plastic entering the ocean, agricultural streams contributed substantially higher amounts than urban outfalls (23.9 particles/min compared with 1.5 particles/min) due to the higher discharge rates in the former (CSUMB 2019). GESAMP (2016) reported that little is known about plastic pollution from agriculture, yet these results indicate its contribution to ocean pollution may be significant in areas where agricultural land use is prevalent.

RELATIONSHIP OF SOURCE, BANK PLASTIC AND MICROPLASTIC FROM SURFACE WATER

Determining the source of MP plastic is difficult for multiple reasons, including the need to determine the chemistry and also the diversity of uses of the same chemistry for multiple products across many sectors. We lacked the analytical equipment (FTIR or Raman) needed to explore the chemistry of the MPs. However, if analytical methods had been available, at best we would have been able to distinguish the chemistry of the plastic and not the origin. The same plastic chemistry is used for multiple products that include agricultural and urban uses (Table 7). For example, polyethylene terephthalate (PET) is used in single use bottles and in plastic clamshell containers for strawberries and salads. Low-density polyethylene (PE) is used in plastic mulch, plastic bags and six pack rings. Once these plastic products weather and fragment in the environment into MPs, unless they have a specialized chemistry, it is no longer possible to associate them with the original product. Furthermore, spectrographic determination of chemistry can be hindered by additives to plastic products for coloration and other properties, weathering of MPs in the environment, a limited reference base for comparison of MP to known polymers, and the shape and surface of the fragment available for analysis (Sutton et al. 2019, CSUMB 2019).

Table 7: A short list of the types of plastic and their uses in urban and agricultural settings.

Abbr.	Plastic Chemistry	Agricultural Uses	Urban Uses
PET	Polyethylene terephthalate	Clamshell containers	Water bottles, food packaging
PA	Polyamide/ nylon	Strapping tape, layer in fumigation tarp	Car tires, clothing, rope
PVC	Polyvinyl Chloride	Irrigation tubing	Plumbing pipe
PP	Polypropylene	Animal exclusion fencing, nursery pots, twine, seed bags, berry boxes	Packaging, textiles, fishing gear, straws
Poly	Polyester	Strapping tape, Clamshell packaging	Textiles
HDPE	High density Polyethylene	Drip tape	Plastic bottles, plastic lumber, crates, rope
LDPE	Polyethelyne	Plastic mulch, plastic bags	Plastic bags, six pack rings
PC	Polycarbonate	Green house sheeting	Construction materials, injection molded containers

The CSUMB 660 (2019) class collected 23 MP particles at 3 of the same agricultural sites we sampled (309QUA, 309SRL, 309GAB) and analyzed them using FTIR, finding that no particles collected at these agricultural sites matched known spectra. The plastic chemistry could not be determined despite use of the analytical equipment, perhaps due to plastic weathering in the field, technician inexperience, or irregular particle surfaces. Even for experienced labs, clear spectra of MPs can be difficult to obtain (Sutton et al. 2019). Although SFEI recommends that MP analysis include Raman or FTIR spectroscopy for the purpose of differentiating plastic from other particles and identifying plastic chemistry (Sutton et al. 2019), the usefulness of these technologies for determining the type of plastic in agricultural landscapes remains unproven. Our techniques were more primitive (heating, poking and observational analysis); however, they served as a low-cost and effective means for distinguishing plastic from other microscopic particle types.

We attempted to draw a relationship between the two types of surveys, macro-plastic on banks and MP in water (Fig. 21). We categorized the materials found in bank surveys by the type of MP that would result from its breakdown and summed these categories in order to draw a comparison. We did not see any clear relationship between bank plastic and MPs found in the adjacent stream (Fig. 21).

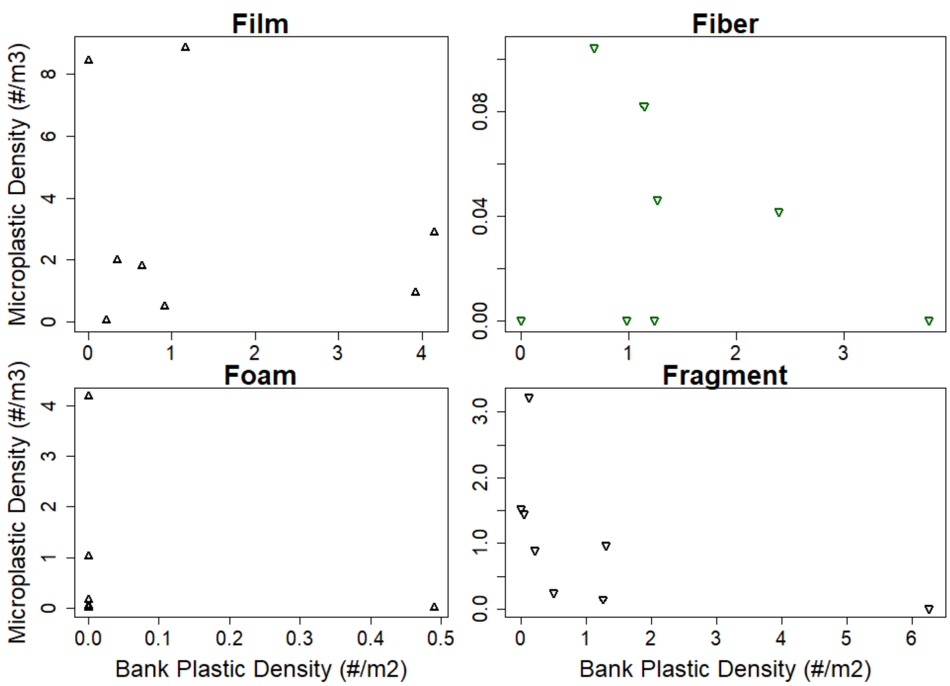


Figure 21: Bank plastic was categorized into the type of microplastic it would become through break down, and compared with the microplastic density found in waterbodies; however no correlation is obvious.

STAKEHOLDER ACTIONS:

What can stakeholders do to reduce plastic pollution? All classes of stakeholders have a role in reducing plastic pollution.

Consumers:

Purchase food grown, shipped and packaged with less plastic:

a) Purchase products sold in recyclable cardboard containers vs plastic
b) Purchase strawberries grown with biodedgradable mulch
c) Ask growers at farmer's markets and CSAs about their plastic recycling program
d) Ask your market to include information on plastic use for produce they sell – so you can be informed.
e) Encourage retailers to sell loose produce (versus plastic wrapped, plastic bagged or mesh bagged) and incentivize consumers for using reusable cloth produce bags
f) Educate consumers about sustainable packaging options (ideally at point-of-sale)
g) Work with store managers and produce managers on a local/regional basis to create sustainable or packaging "lite" section – e.g. "Farmstand" bushels with loose produce and cotton bags with store logo on them; recyclable cardboard packaging; feature local growers and producers who are leading the way, etc.

Growers:

Purchase products with recycled content, e.g., drip tape that has recycled plastic content.

Purchase supplies that can be recycled: drip tape, strapping tape, other.

Include recycling rate in sales and marketing strategy so environmentally conscientious consumers will prefer your products.

Form local groups to set up recycling drop off centers so you can meet the volume/weight minimums for recyclers who will pick up plastic.

Avoid using plastic for ditch lining and exclusion fencing whenever possible.

Researchers:

Design research projects that can help reduce agricultural plastic use, through replacement with other alternatives.

Include results online so that they are accessible to those looking for solutions.

Sustainability Certification Organizations:

Develop and promulgate standards and metrics that will encourage plastic recycling and replacement with alternative products for all types of agricultural plastic. Help growers know about alternatives and where/how they can recycle.

Regional Waste Management Facilities

Encourage increased recycling of agricultural plastic products through creating drop off locations at the facility, from which separated plastic could be sent to a recycling facility.

Provide information on recycling to growers when they drop off plastic so that they can minimize what goes to landfill.

Students, Entrepreneurs, Collaborators

Design and develop local recycling and replacement solutions for agricultural plastics. Create systems to collect, separate and recycle plastic where there are not current local alternatives. Help growers use these systems.

Organize plastic clean up days and volunteer to help remove plastic from fields and stream banks.

Sellers

Provide information regarding product recycling to purchasers so that they can make an informed buying decision.

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Appendix A

OVERALL AGRICULTURE PLASTIC STRATEGY RECOMMENDATIONS FOR CMSF

Focus attention on the largest use plastics in Monterey County: irrigation tubing, mulch film and fumigation film. And on the plastic types found on stream banks and waters: film, strapping tape and slow release fertilizer pellets.

REFLECTIONS ON THE STUDY

This study provided quantification of field plastic. Plastic used in fields is susceptible to breakdown by the sunlight, wind and machinery. Fragments in the open environment can be transported by wind and water to streams. From highest to lowest amount used by weight, field plastic is ranked: 1) Irrigation tubing over 12 million lb./yr., 2) Film (mulch and fumigation) over 8 million lb./yr., 3) hoop houses over half a million lb./yr. PE mulch and TIF fumigation film lack a recycling option.

Bank trash surveys indicated that films are the most prevalent kind of plastic waste found. The second highest contributor to plastic waste was strapping tape.

Microplastic found in streams in agricultural areas found that film, fiber, fragments and pellets originate from agricultural sources that travels from streams to MBNMS. Slow release fertilizer pellets were the largest contributor to MP pollution in streams.

Recommendations

PE MULCH

Plastic mulch should be a priority for CMSF as it is probably the foremost ag plastic contaminant to the Monterey Bay National Marine Sanctuary due to the magnitude and geographic extent of PE plastic mulch use, tendency to break and fragment, inability to recycle, and light weight that allows conveyance by wind or water to streams and on to the ocean.

1. CMSF should support the work of WSU, local UCCE and Cal Poly researchers on BDM field trials in CA strawberry production as this represents the major ag user of PE mulch.
2. Phase 1: Data collection: Approximately 5 growers have agreed to trial BDM on their ranch in fall 2020 on a small section. Two types of BDM are being used for the trials, along with traditional mulch or TIF. It is important to collect data and grower feedback during the trial. This will involve the following tasks:
    a. pre-trial soil sampling to collect data on current PE plastic content in the trial field (approx. 12 hours per field – I can likely get help),
    b. bi-monthly photo monitoring of percent soil exposure (PSE) at all sites to evaluate BDM physical degradation and condition (16 hours per month),
    c. mesh bag burial using field-weathered BDMs to assess rate of in-soil biodegradation under California conditions,
    d. survey of growers to get feedback at various points to understand bridges and incentives to BDM adoption (laying of mulch, planting of strawberries, 3 months after planting, at end of season, and after plowing under). Approximately 8 hours per session or 40 hours total.
    e. Attend 1 – 3 growers mulch laying to video tape the process (4 hours each),

f. Soil sampling after 2 years to assess biodegradation by quantifying the amount of visible plastic fragments in soil

3. Group review of trials with Mark Bolda, Lisa DeVetter, Geo Rich, Sita Sistla and growers to insure we understand grower assessment of trial and suggestions going forward. (Design, coordinate, attend – 16 hours)
4. Phase 2: Outreach with results – strawberry meeting. Convey the outcome of the trials to a broader group and continue to progress with implementation on more acreage and more growers (assuming Year 1 goes well).
5. CMSF should continue to participate in USDA Specialty Crop Research Initiative (SCRI) planning with the multi-functional team that is proposing a grant to research the feasibility of BDM in strawberry production in CA. CMSF should consider helping write this grant. Also the organization needs to determine its role in the project and what funding to request.
6. BDM should continue to be explored as an option that CMSF may decide to recommend and promote with education and outreach following the research trials and into the future. Issues remain regarding use in conventional crops as it is not currently a replacement for fumigation tarp. Because it is not approved by the NOSB, it cannot currently be used in organic production. Also adoption can be tricky to gain, so we need to understand the grower perspective as well as potential for pull through marketing.
7. Methods for PE plastic removal and recycling is also an avenue worth continuing to explore through participation in SCRI and with local recycling and waste management facilities.
8. CMSF should develop talking points and determine its position re how strongly to be involved in discussions/ letters to the NOSB regarding acceptance of BDM.
9. BDM's impact on soil health remains in question and should be investigated. So far it apparently adds to soil carbon (a good thing) and has some effect on the microbial community.

FUMIGATION FILM

1. Continue to participate in SCRI planning and grant.
2. Encourage testing of Biodegradable mulch with fumigation to find its permeability.
3. Follow ASD research to find out more about disease control, economics and issues to adoption.
4. Follow fumigation legislation to stay abreast of changes in regulation.

STRAPPING TAPE

Pursue strategies to reduce the amount of strapping tape that is not properly disposed:

1) Research grower requirements for strapping tape and why so many types are used. Research solutions and current capabilities of recyclers and manufacturers to see if it is possible to consolidate to fewer types.

2) Determine a recommended solution of type of strapping tape to purchase that we think would be universally accepted, how & where to recycle it, equipment needs of the grower, etc.

3) Develop an on farm system for collection & disposal of strapping tape, preferably to a recycler and test the system in 2-3 grower operations. Strapping tape is also a big waste issue in distribution facilities per Measure to Improve. Maybe there is a small business potential in here that we could recommend to MIIS or CSUMB students?

4) Track costs and benefits,

5) Develop a strategy for expanding across the grower community. Utilize Measure to Improve ($185/hr) to help create momentum with growers and distributers.

IRRIGATION TUBING

1) Develop a strategy for achieving 100% recycling.
2) Collect information on recycling, pickup locations, apps for requesting pick up, and products with recycled content in order to develop an informational brochure.
3) Work to create locations for centralized pick up for growers that do not meet minimum standard.
4) Ask suppliers, MRWMD, Grower Shipper, Farm Bureau, RCDs, AWQA and other organizations and websites to provide these brochures to growers.
5) Encourage growers to preferentially purchase irrigation products with some recycled content, as creating a market for recycled materials is one of the largest issues impeding higher rates of recycling (L Valdez – Revolution Plastic personal communication).
6) Evaluate methods for complete removal from the field and include this information in the brochure.

SLOW RELEASE FERTILIZER PELLETS

These were the single largest number of MPs found in streams.

1) Evaluate effectiveness of slow release fertilizers. Have heard some say they don't really work well
2) Contact fertilizer manufacturers to find out whether they are pursuing biodegradable alternatives.
3) Find out whether these plastics decompose through time.
4) Inform growers of our MP findings and encourage them not to fertilize prior to rain or irrigation events that could transport these pellets. However since the pellets may be made to last several months, one cannot expect likely exposure to water transfer offsite during this time period.