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Using Vegetation to Reduce Nitrogen Runoff in California Caneberries

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USING VEGETATION TO REDUCE NITROGEN RUNOFF

IN CALIFORNIA CANEBERRIES

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ABSTRACT

USING VEGETATION TO REDUCE NITROGEN RUNOFF IN CALIFORNIA CANEBERRIES

By Rebecca I. Riesenfeld

With a 700% rise in global fertilizer use in the last 50 years, agricultural lands are a significant source of nitrogen and phosphorus pollution in aquatic ecosystems worldwide. Record high levels of nitrate-contaminated runoff from agricultural sources in California's Central Coast are affecting drinking water supplies in the Pajaro Valley and increasingly threatening the ecological health of the Monterey Bay. Bands of vegetation strategically planted to control runoff and soil erosion, or vegetative filter strips (VFS), are used in urban landscapes and at some farm peripheries. On-farm vegetative diversity has been promoted for its contribution to biodiversity and pest control. The efficacy of in-row VFS for nutrient removal, however, has never before been explored in caneberries, the fastest-growing agricultural commodity in Central California. This on-farm study experimentally tested the ability of three different types of common and native VFS planted between the rows to reduce nitrogen runoff in California caneberry fields: California field sedge (*Carex praegracilis*), creeping wild rye (*Leymus triticoides*), and wild mustard (*Brassica juncea*). Overall, nitrates in runoff decreased significantly with greater VFS cover. Of the three species tested, *L. triticoides* grew fastest, but *B. juncea* yielded the greatest cover by the end of the rainy season. VFS were shown to be a cost-effective tool that growers can use in California caneberries to decrease nitrate runoff while inherently promoting on-farm biodiversity.

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Lastly, I would like to thank my unselfish and loving husband Joe, who assisted in all aspects of the project, particularly with the construction and maintenance of the sampling apparatuses, and who maintained the many abandoned facets of our life while I was regularly up to my knees in mud or somewhere along Highway 101.

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INTRODUCTION

Agricultural lands are a significant source of nitrogen and phosphorus pollution in aquatic ecosystems today. Advances in technology and water resource management have led to a 70% increase in irrigated cropland and a 700% rise in global fertilizer use in the last 50 years (Foley *et al.* 2005). Nutrients from fertilizer flow into waterways and leach into groundwater supplies. In fact, nitrate is the most common contaminant in groundwater aquifers worldwide (Spalding and Exner 1993).

Nonpoint source pollution (NPS), also known as runoff, from agriculture is the most widespread water quality problem in the United States (USEPA 2014). Statewide, nutrients are the third most common, and in heavy agricultural areas, nutrients are the second most prevalent NPS water pollutant (USEPA 2014). Of the total nitrate pollution in California's Central Coast, 96% comes from cropland, with 54% from synthetic fertilizer and 33% from animal manure (Harter *et al.* 2012). The average crop today takes up only 30% to 50% of applied nitrogen fertilizer (Cassman *et al.* 2003; Smil 1999) and about 45% of phosphorus fertilizer (Smil 2000). Excess nitrogen (N) and phosphorus (P) from agricultural runoff cause algal blooms in aquatic systems, leading to harmful effects, such as hypoxia, waterborne disease, fish kills, and loss of economic revenue from associated services. Elevated levels of nutrients in drinking water pose critical threats to humans, including blue baby disease (methemoglobinemia) and gastric cancer (Dowd *et al.* 2008).

As one of the most biologically diverse temperate regions in the world, the Central Coast of California is home to numerous environmental treasures, including the

Monterey Bay National Marine Sanctuary, one of the largest marine sanctuaries in the world, and the Elkhorn Slough Estuarine Research Reserve, one of the largest remaining tidal wetlands in the United States (Dowd *et al.* 2008). The region provides critical habitat for the last remaining population of the California sea otter, endangered steelhead, endangered coho salmon, and the endangered red-legged frog. As the nation's third highest grossing agricultural area (Klonsky and Tourte 1998), the Central Coast generates more than five billion dollars a year (USDA-NASS 2013). Approximately 200 major crop varieties are grown and harvested, including lettuce, berries, broccoli, cauliflower, grapes, and apples (USDA-NASS 2013).

Exacerbated by the region's relatively short growing cycles, frequent tillage and cultivation, and the low nutrient uptake efficiency of various crops (Dowd *et al.* 2008), farm-based runoff is threatening the ecological health and agricultural viability of the Central Coast. The main river in the Pajaro Valley watershed, the Pajaro River, and many of its tributaries are listed as impaired for sediment and nutrients under California's 2002 Section 303(d) of the 1972 Clean Water Act (Beretti and Stuart 2008). In 2011, the Obama Administration selected the Monterey Bay region as one of three nationally targeted areas for extensive conservation efforts outlined in *America's Great Outdoors Initiative* (Salazaar *et al.* 2011). Sites were chosen for their economic, cultural, and ecological importance to the United States, as well as for their environmentally impaired status.

Over half of California's $11 million berry crop is grown in the Central Coast region, helping to make the state the top berry producer in the nation (USDA-NASS

2013). Berry cultivation, including strawberries and caneberries, is a significant source of sedimentation and nutrient runoff (Dowd *et al.* 2008). The crop is grown in highly erosive, sandy soils, and often planted up to the edge of sensitive wetlands. Additionally, fertilizer containing concentrated amounts of both nitrogen and phosphate is used to enhance yields and prolong fruit production beyond the traditional harvest season.

Bands of vegetation strategically planted to reduce runoff and soil erosion, or vegetative filter strips (VFS), have been proposed by numerous authors as a method to reduce nutrient concentration in farm runoff. In some systems, VFS have been shown to effectively trap 75% to 100% of sediment runoff (Dillaha *et al*. 1989; Grismer *et al.* 2006; Tourte *et al*. 2003), capture up to 83% of nutrients through both plant uptake and adsorption to soil particles (Leeds *et al.* 2007), decrease waterborne pathogens (Dillaha *et al.* 1989; Knox *et al.* 2007; Tate *et al.* 2006), and improve water quality (Dowd *et al.* 2008). VFS are effective because they provide greater surface roughness, increasing infiltration of water in soil and decreasing runoff volume and speed (Borin *et al.* 2005; Grismer *et al.* 2006). As a result, transport capacity is reduced, promoting sediment deposition and nutrient capture (Grismer *et al.* 2006).

LITERATURE REVIEW

The loss of sediment and nutrients from agricultural fields poses significant problems for water quality. Conservation buffers have demonstrated the ability to remove nitrates (Lee *et al.* 2003), adhere phosphorus (Sharpley and Withers 1994), trap sediment (Dillaha *et al.* 1989; Karr and Schlosser 1978) and remove pesticides (Correll 1996). More recently, buffers have been noted for their promotion of biodiversity and general ecosystem health (Dowd *et al.* 2008) and filtration of waterborne bacteria (Tate *et al.* 2006). Yet despite this research, VFS have not been widely implemented. In this literature review, I take a deeper look into the history, structural properties, mitigation capabilities, and potential problems of VFS to help explain this complex situation.

History of Water Quality Regulation in the United States

Historically the United States government was not involved in governing water quality, but in 1948 the landmark environmental law, The Federal Water Pollution Control Act (FWPCA) was passed. Although the FWPCA comprised the framework for the management of point source air and water pollution, the law was largely ineffective. In 1972, FWPCA was expanded in response to the nation's increasing awareness of environmental degradation and water pollution. One of the most effective expansion measures established the National Pollutant Discharge Elimination System, an intricate system of required permits and emission records for all polluters, granting the United States Environmental Protection Agency (USEPA) the legal authority to set and enforce effluent levels. The FWPCA was amended once again in 1977 to become the Clean Water Act of 1977 (Kubasek and Silverman 2010).

While the Clean Water Act amendments addressed many important aspects of water pollution that had been previously overlooked, NPS pollution was still absent from any legislation (Kubasek and Silverman 2010). NPS water pollution occurs when rain or snowmelt travels over or through land picking up chemicals and contaminants. NPS water pollution is particularly difficult to regulate because of the diffuse nature of its various sources (USEPA 2014).

Prompted by numerous scientific reports linking NPS pollution and contaminated water, The Water Quality Act of 1987 was added to The Clean Water Act. As the first environmental legislation directly aimed at addressing NPS water pollution (USEPA 2014), the Water Quality Act attempted to provide methodologies to answer the difficult questions associated with NPS, such as determining the particular contaminant type, its exact quantity, the and responsible party (Kubasek and Silverman 2010). While the Water Quality Act focused mainly on mitigating urban stormwater runoff, it neglected to address agricultural runoff (USEPA 2014).

Managing agricultural runoff still remains largely a voluntary process. In the last 25 years, the USEPA and United States Department of Agriculture – Natural Resources Conservation Service (USDA-NRCS) have established many programs assisting farmers with mitigation of agricultural waste; however, the economic burden is often placed on the grower, reducing incentives for program implementation. Although regulatory measures for particular contaminants, such as pesticides and nutrients, are slowly being established, it is still too early to evaluate any potential progress in the reduction of agricultural NPS water pollution (Ribuado *et al.* 2010).

Conservation Buffers

Conservation buffers are areas of natural or managed vegetation used to mitigate NPS pollution through the removal of sediment and other contaminants. Often referred to as vegetative buffer zones, conservation buffers are frequently long areas of vegetation adjacent to waterways, ponds, or lakes that separate human activities from natural resources. Conservation buffers are most commonly composed of perennial plants because the extensive root systems of perennials stabilize soil, promote deeper infiltration of water, and effectively trap sediment (Carpenter *et al.* 1998). In addition to sedimentation reduction, conservation buffers also improve water quality and protect watershed areas by helping to remove nutrients and pesticides in field runoff (Dillaha *et al.*1989; Lee *et al.* 2003; Lovell and Sullivan 2006).

History of Conservation Buffers

Although the term *conservation buffer* did not emerge until the late 1970s, buffers have been used in agriculture for millennia. Riparian forests, wetlands, and hedges were prevalent in agricultural landscapes until the 19th century in Europe (Vought *et al.* 1995), and remained in the rural landscape even after much of the land had been settled and cultivated in the United States (Lovell and Sullivan 2006). These features were employed for several reasons, including establishing property boundaries, containing livestock, and aesthetic preferences (Lovell and Sullivan 2006).

The intensification of agriculture and the introduction of clay drainage tiles in the mid-1800s promoted large-scale replacement of natural buffers with crops (Vought *et al.* 1995). During this same period of time, farmers first noted the seriousness of soil erosion due to continuous farming. Although some farmers independently employed conservation buffers such as hedges, stonewalls, and hillside ditches, it was not until the late 1920s when soil erosion was recognized as a national threat to food security (Bennett 1939).

In 1933 the Soil Erosion Service was established in the United States Department of the Interior to promote research and solutions for managing soil erosion. The Great Dust Storm of 1934 worsened the existing problems experienced in the U.S. from soil degradation and erosion (Lovell and Sullivan 2006). In the landmark book, *Soil Conservation,* Bennett (1939) introduces such practices as vegetative ditches, contour strip cropping, retention of forested areas, and planting trees to help control stream bank erosion.

These practices became increasingly recognized for their effectiveness, and in the 1970s researchers began to look at the water quality benefits of conservation buffers (Correll 1996). In 1985, the USDA-NRCS established the Conservation Reserve Program (CRP), which pays rural landowners to designate parts of their land for conservation buffers (Ribuado *et al.* 2010). The CRP began in 1986 by enrolling highly erodible cropland and retiring it from production for 10 to 15 years. In addition to the CRP, the USDA-NRCS has developed programs, including the Conservation Steward Program, Conservation Effects Assessment Program, and the Environmental Quality Incentives Program, to work closely with farmers to help implement best management practices. Local governing bodies, such as the State Water Resources Control Board and the Central Coast Regional Water Quality Control Board (CCRWQCB), also work to address issues pertaining to water quality, soil erosion, nutrient runoff, and eutrophication.

Types of Conservation Buffers

There are many different types of vegetative buffers, including wetlands, riparian vegetation, forest systems, and filter strips. Often, various types of buffers are used in conjunction with each other. For example, a banded or integrated design of VFS establishes alternating grass and tree buffers. In their experiment, Duchemin and Hogue (2009) successfully achieve sediment and nutrient runoff capture through a "three zone buffer system" composed of grass, riparian, and forest buffers.

Natural or constructed wetlands play an important role in farm runoff treatment. These robust wetlands provide cleaner water, runoff and flood management, odor minimization, and enhanced biodiversity. Constructed wetlands are generally more expensive to implement than other types of buffers, although the cost is still relatively low when compared with other mitigation methods, such as pump and treat. Disadvantages of constructed wetlands may include some infiltration of contaminated water to ground water and the emission of greenhouse gases (Carty *et al.* 2008).

By helping to maintain the structure and function of stream ecosystems, riparian buffers minimize the amount of polluted runoff entering aquatic habitats (Barling and Moore 1994). Riparian vegetation also reduces sediment erosion through the stabilization of stream banks, increases the natural resistance to flow from plant debris, and lowers water temperatures by providing shade. Lastly, riparian vegetation supports biodiversity by creating food sources and natural shelter for in-stream fauna.

Forest buffer zones are defined as strips of undisturbed forest along waterways to protect water quality (Barling and Moore 1994). As the environmental degradation associated with logging practices became more well known, forest buffers were publicized as a solution for the protection of the surrounding environment, as well as the logged areas. Forests are particularly efficient buffers because the high soil moisture and concentration of organic carbon create a sink for constant input of nitrate from surface and subsurface flows (Vought *et al.* 1995).

Unlike many wetlands, riparian buffers, or forest buffers that frequently occur naturally, VFS are intentionally planted areas targeted for mitigating of NPS water pollution (Dillaha *et al.* 1989). VFS are used for contaminant reduction in both urban and agricultural areas. Depending on the environmental constraints and overall objective, VFS may vary greatly in composition and vegetation type (Verstraeten *et al.* 2006).

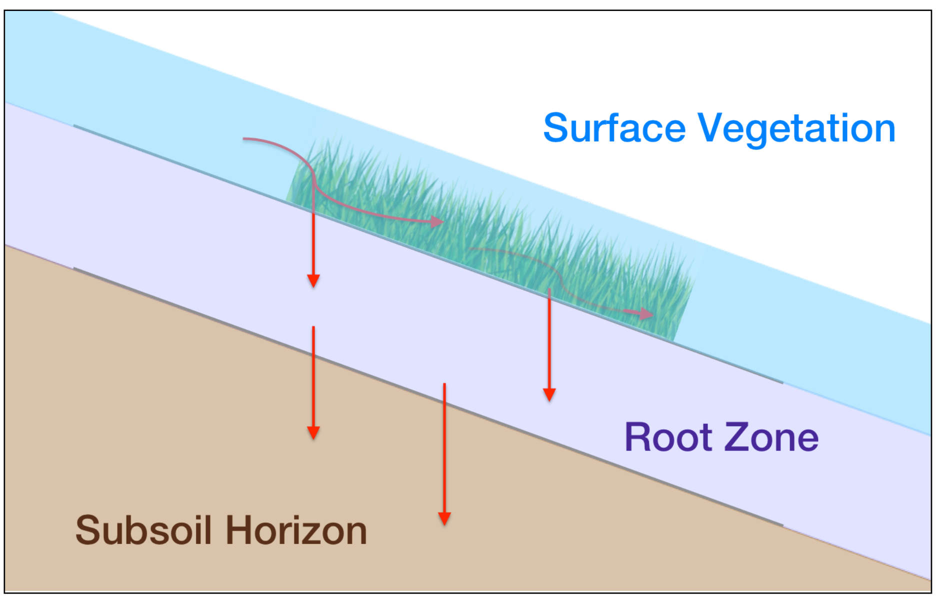

Figure 1. Three distinct zones of vegetative filter strips .

Vegetative Filter Strips (VFS)

VFS consist of three distinct layers: surface vegetation, root zone, and subsoil horizon (Figure 1). By increasing surface roughness, VFS create more opportunities for infiltration of water into the ground, and reduce the speed of runoff (Borin *et al.* 2005; Grismer *et al.* 2006). Slower flow velocity leads to reduced transport capacity and eventually sediment deposition in VFS (Grismer *et al.* 2006). Contaminants such as N, P, and certain pesticides like pyrethroids, strongly bind to soil particles, allowing for successful removal when sediment is trapped and retained. Moreover, VFS can enhance nutrient uptake through vegetative hyperaccumulators (Ishikawa *et al*. 2006; Tourte *et al.* 2003), promote degradation and transformation of pollutants into less toxic forms, and remove over 60% of certain pathogens, including *E. coli*, from runoff (Knox *et al*. 2007; Tate *et al.* 2006).

When determining the most effective VFS for an area, it is important to evaluate environmental characteristics, such as runoff velocity, discharge volume, sediment properties, and average amount of rainfall before installing VFS designs (Verstraeten *et al.* 2006). Key parameters include vegetation, maintenance, slope, and placement (Grismer *et al.* 2006).

Vegetation

When designing VFS, choosing the correct type of vegetation is important for success (Grismer *et al.* 2006). Depending on factors like plant growth rate and nutrient concentration in plant tissue, nutrient uptake varies widely among species (Merhaut *et al.* 2013). Plant type influences transpiration rates and soil microbial communities, which are instrumental in the biological uptake of N (Balestrini *et al.* 2011). Rapidly growing vegetation is easier to establish and can take in more nutrients, but it requires more maintenance, such as pruning and mowing. Plant species in the genus *Carex* have been proven capable of successful nutrient removal in edge-of-field filter strips (Karlik *et al.* 2009; Palmer 2012). The naturally low-growing California field sedge (*Carex praegracilis*) survives moderate foot traffic and endures temperatures as low as -12 ºC (10 ºF) (Figure 2). The denseness of the fine root structure of the *Carex* species provides substantial surface area for nutrient uptake. While requiring only minimal maintenance, this *Carex* species is tolerable of both drought and saturated conditions (Bratieres *et al.* 2008).

Figure 2. California field sedge (*Carex praegracilis*).

Leymus triticoides is a rhizomatous, turf-forming grass that can reach up to 1.3 m (Figure 3). Sometimes used to stabilize waterways, *L. triticoides*, is highly adaptable to coldness, dryness, and saline or alkaline soils (Comer *et al*. 2006). Disease and insect resistance have also been noted among the species characteristics (Yang *et al.* 2008). A native perennial grass in California, *L. triticoides* plays an important role because it resists takeover from invasive species (Lulow 2006). This property is helpful for initial growth and establishment in the vegetative filter strips, especially when competing with farm weeds present in rainy season months.

Figure 3. Creeping wild rye (*Leymus triticoides*).

Figure 4. Wild mustard (*Brassica juncea*).

A species of the mustard plant, *Brassica juncea* is a cool-season annual that can withstand temperatures as low as 20 °F (-4 °C) without damage (Figure 4). Njoroge *et al.* (2007) and Shennan *et al*. (2007) both report that *Brassica* seed meal and cover crops may have anti-fungal properties that either kill or inhibit the growth of many pathogenic soil organisms. Mazzola and Zhao (2010) and White and Brown (2010) studied three species of Brassica, including *B. juncea*, and documented suppression of apple replant disease. Additionally, *B. juncea* has been widely implemented to extract heavy metals

(Ishikawa *et al.* 2006; Salido *et al*. 2003), but few studies have examined its ability to uptake nutrients in VFS.

Maintenance

VFS can require relatively little maintenance. VFS upkeep is largely limited to keeping proper vegetation cover, removing excess sediment, and occasional irrigation, if necessary. Maintenance for VFS may also entail control of noxious weeds, occasional harvest or mowing of vegetation, and limitation of traffic within filter strips (Grismer *et al.* 2006).

Slope and Width

Slope and width are correlated because steeper slopes often require wider VFS. Although the USDA-NRCS publishes official agricultural standards and regulations, the optimal width of VFS is not uniformly established (USDA-NRCS 2011). Some experts advocate 10 m wide VFS (Abu-Zreig *et al.* 2004; Castelle *et al.* 1994; Stutter *et al.* 2009), while others have shown effective removal using VFS of less than 10 m (Balestrini *et al.* 2011; Borin *et al.* 2005; Dillaha *et al.* 1989; Schmitt *et al.* 1999).

For soluble compounds, such as nutrients, removal tends to be proportional to width of VFS (Geza *et al.* 2009; Schmitt *et al.* 1999) until a certain width, and then the incremental gains in efficiency decline (Baker and Michelson 1994; Schmitt *et al.* 1999). For example, Abu-Zreig *et al*. (2004) published results of sediment trapping efficiency of 68% for 2 m wide VFS and 98% for 15 m wide VFS. However, when Abu-Zreig *et al.* (2004) looked at the data more closely, the sediment trapping efficiency between 10 m VFS and 15 m VFS show no appreciable difference. Similarly, Schmitt *et al.* (1999)

found sediment concentration was reduced by 87% to 93% in 15 m wide VFS; however, the majority of the reduction (76% to 89%) occurred within the first 7.5 m.

Nutrient and pesticide removal rates and buffer widths are more variable that removal rates for only sediment (Baker and Mickelson 1994; Dillaha *et al.* 1989) because nutrient removal is a more complex process. Whereas sediment removal depends mostly on vegetative cover, nutrient removal is determined by electromagnetic charge and exhibits a tendency to form soil-bound particles, nutrient solubility, plant uptake, soil microbial communities, vegetative cover, and hydrologic conditions, as well as VFS width (Grossman and Brown 2007; Lee *et al.* 2003; Magette *et al.* 1989; Vought *et al.* 1995). In their study examining cropland runoff, Dillaha *et al.* (1989) found VFS with widths of 4.6 m and 9.1 m to have an average sediment trapping efficiency of 70% and 84%, respectively. However, the nutrient removal rate for nitrates and phosphates, respectively, were 61% and 75% at 4.6 m, and 61% and 87% for 9.1 m width VFS. Parsons *et al.* (1994) found that only 26% of phosphates and 50% of nitrates were removed in 5.3 m wide VFS.

Dabney *et al.* (2006) argue that length of the buffer strip is more important than the width because of its nonlinear relationship to sediment trapping and nutrient removal. Since the first increment of buffer has a larger impact than any subsequent one, runoff behind it is likely to try to find a way around the buffer. Consequently, Dabney *et al.* (2006) stress the importance of a continuous buffer edge.

Placement

Proper placement can greatly increase VFS effectiveness. Geza *et al.* (2009) found that it was more effective to place small VFS in as many land units as possible, compared to installing larger VFS on only a few selected fields. Similarly, when VFS were placed further from the contamination source and closer to rivers and streams, Verstraeten *et al.* (2006) found that VFS were largely ineffective due to flow convergence. Therefore, it is more effective to place VFS as close as possible to the contamination source regardless of riparian distance, as opposed to further away from the source and closer to a targeted river or stream (Verstraeten *et al.* 2006).

In their comparison of in-field, edge-of-field, and after-field buffers, Dabney *et al.* (2006) found in-field buffers that were oriented close to the contour or along the slope were best at reducing runoff, controlling erosion, and stopping pollution transport. Although in-field buffers offer the best opportunity to encounter sheet flow of runoff; they may be difficult to implement and maintain because of the placement in high traffic areas. Edge-of-field buffers eliminate many of the complications of in-field buffers, but pose restrictions of specific grade requirements (USDA-NRCS 2011) because they are located down slope of the treated fields. A gradient restriction of less than 0.5% for an up-slope field between 1% and 10% is recommended because of the potential for berms and subsequent flow redirection. A combination of in-field and edge-of-field VFS with after-field vegetated ditches may be the most effective placement of vegetative buffers (Dabney *et al.* 2006).

Although VFS are widely promoted in agricultural applications, little or no evidence exists that they are used by caneberry producers. Barriers to VFS adoption commonly include a lack of economic incentives (Ribaudo *et al.* 2010), lack of knowledge about different species in different systems (Schmitt *et al.* 1999), aesthetic perception (Lovell and Sullivan 2006), and even food safety concerns (Beretti and Stuart 2008). With further investigation, VFS may prove to be a viable, cost-effective part of the solution.

PROBLEM STATEMENT

California's Central Coast is at a critical turning point. Historically, the incentives for farmers to mitigate runoff have not been substantial enough to outweigh the economic costs (Ribuado *et al*. 2010; Tourte *et al.* 2003); however, this is quickly changing. For the first time, the 2004 Agricultural Waiver of California mandated water quality testing and implementation of Best Management Practices (CCRWQCB 2012). In 2011, the CCRWQCB found that since the issuance of the 2004 Agricultural Waiver, conditions in agricultural areas continue to be severely impaired. The CCRWQCB found the most serious water quality degradation is caused by fertilizer and pesticide use (Harter *et al*. 2012), and has declared efforts to mitigate and control agricultural waste discharge are among the top priorities due to the significance and urgent nature of the problem (CCRWQCB 2011).

Several studies have shown VFS effectively trap 75% to 100% of sediment runoff (Dillaha *et al.* 1989; Grismer *et al.* 2006; Lee *et al.* 2003); however, the majority of these studies have been performed in controlled systems that do not accurately represent realistic conditions. Furthermore, few studies had been conducted with VFS and berry fields, and none in the Pajaro Valley Watershed.

In order to determine the effectiveness of VFS for berry runoff in the Central Coast, more research is needed. Past studies have analyzed the effectiveness of VFS by using simulated sheet flow runoff in closed-field settings. Recent model-based research has shown that convergence of runoff may substantially alter flow patterns (Dosskey *et al.* 2011; Rudra *et al.* 2010). Since caneberry fields are designed with ridges and furrows, small channels and tillage-induced berms are likely to cause flow convergence. As a result, experimental studies using actual field conditions are needed to analyze the mitigation capabilities of VFS. This study investigated the effectiveness of three different kinds of VFS for reducing soil erosion and nutrient runoff from raspberry and blackberry fields into the Monterey Bay.

Research Questions and Hypotheses

Q_1: Can VFS reduce nitrogen runoff from caneberry fields?

- H_{1a}: Higher quality VFS cover in caneberry fields will reduce N and P levels in farm runoff.
- H_{1b}: Within-row VFS presence will reduce N and P levels in farm runoff as compared to unvegetated controls.

Q_2: Is one type of vegetation more effective than the others?

- H_{2a}: *L. triticoides* will demonstrate greater N and P uptake in runoff than *C. praegracilis* and *B. juncea.*
- H_{2b}: *L. triticoides* and *C. praegracilis* planted as plugs will grow more vigorously than broadcast *B. juncea.*

Q_3: Do the economic benefits outweigh the costs?

- H_{3a}: VFS are a cost-effective approach for growers to decrease nitrate levels in compliance with the *2012 California Agricultural Waiver*.
- H_{3b}: Broadcast *B. juncea* will be more cost-effective as a VFS than *L. triticoides* and *C. praegracilis* planted as plugs.

METHODS

Study Site

The study was conducted on caneberry fields in the Pajaro Valley of California's Central Coast. Approximately 150 km (93 mi) southeast of San Francisco, the site is located near the town of Watsonville in Santa Cruz County. All farms in Watsonville and surrounding areas are in the Pajaro Valley Watershed, which encompasses about 2,000 km^2 (1,200 mi^2) and drain into the Monterey Bay.

Study Design

Three VFS vegetation types: California field sedge (*Carex praegracilis*), creeping wild rye (*Leymus triticoides*), and wild mustard (*Brassica juncea*) were planted in VFS plots at the end of caneberry rows. Vegetation species were selected for robustness, uniform growth, nutrient uptake, root infiltration, and regional compatibility characteristics. No vegetation types were mixed.

Vegetation was planted by plugs or broadcast seeded at the edge of the caneberry row creating an in-field VFS of approximately 6 m (20 ft) in length and 2 m (2.5 ft) in width. Prior to planting, the rows were tilled and vegetation other than the caneberries was removed. Plugs for *C. praegracilis* and *L. triticoides* were purchased from Hedgerow Farms (Winters, CA) and planted 12 June 2012 to allow time for plant growth and root establishment. *B. juncea* seeds, purchased from Johnny's Selected Seeds (Fairfield, MA), were sown in October 2012. Control plots remained bare. In each row, vegetation was planted between caneberry plants in the furrow area of the row approximately 6 m (20 ft) in from the end of the row.

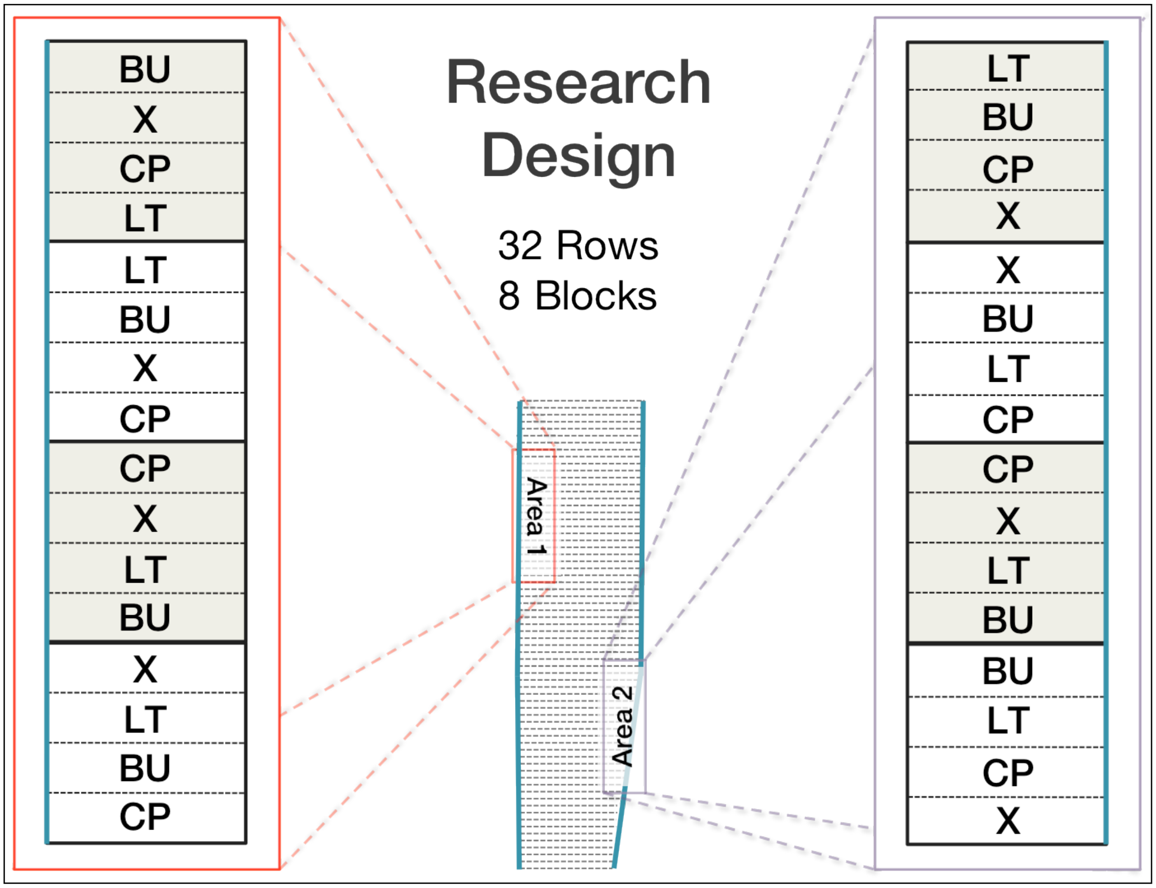

Figure 5. Schematic diagram of original research design (not drawn to scale); BU - *B. juncea*, CP - *C. praegracilis*, LT - *L. triticoides*, X - Control.

The randomized block study design consisted of 32 experimental rows divided into 8 blocks of 4 treatments (Figure 5). Each block contained 1 replicate of each of three vegetation treatments and 1 unvegetated control. Randomization of placement was achieved by enumerating all 24 possible permutations within a replicate, then using the Excel (Microsoft Corporation, Redmond, WA) random number generator to assign a permutation to each replicate, which translated into positions of vegetation types. The experimental area was further divided into two sections: Area 1 and Area 2, of 4 blocks

(16 rows) each. Slope was perpendicular to treatments so no runoff went from one row to another and as a result, contamination of samples was not a problem.

On 11 February 2013 some rows were accidentally disked leaving vegetation tilled and uprooted, and sampling apparatuses destroyed. Luckily, the anchor rows, named for the semi-permanent posts that support the tunnels, were spared because the tractor could not pass through the many large metal posts throughout the row in the middle of the row. Since the non-anchor rows were no longer usable for the study, the focus shifted to look at only anchor rows for the remainder of the rainy season from 12 February 2013 to 15 April 2013 (Figure 6). Every third row was an anchor row, and remarkably, treatment types were relatively evenly represented in the breakdown of the 11 spared anchor rows. Unfortunately, placement and replication were irretrievably limited to two *B. juncea*, three *C. praegracilis*, three *L. triticoides*, and two control plots, severely limiting statistical power. One additional control trap was sunk into the ground in R34 in Area 2 boosting the total number of sampled control plots to three.

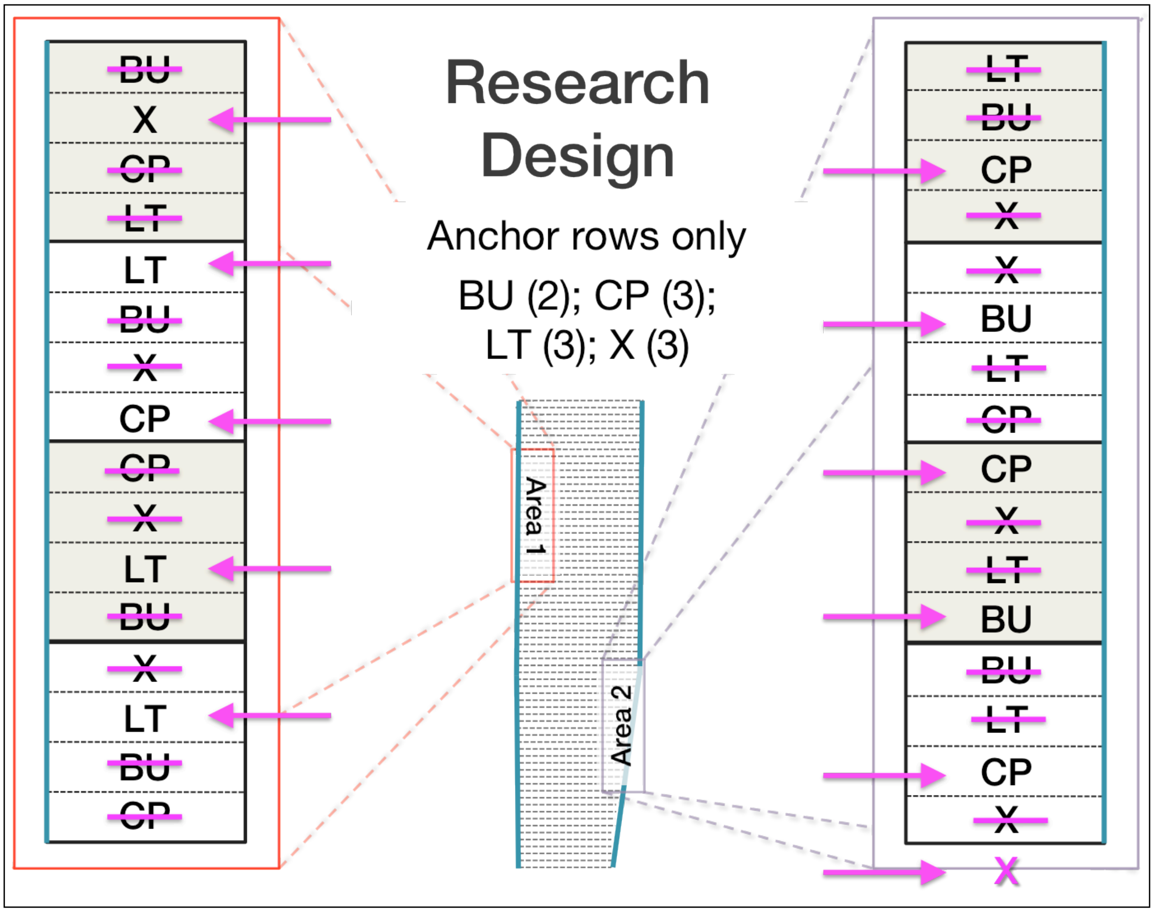

Figure 6. Schematic diagram of revised design (not drawn to scale); BU - *B. juncea*, CP - *C. praegracilis*, LT - *L. triticoides*, and X - Control.

Sampling apparatus

Custom surface nutrient runoff sampling apparatuses were developed in consultation with a range of practitioners and researchers (Figure 7). The base of each sediment/runoff trap consisted of 1 32-gallon Brute™ (Newell Rubbermaid, Atlanta, GA) garbage can with a silicon-sealed funnel lid buried deeply enough in the ground that the top rim of the can was even with the grade level. Positioned in the center of the silicon-sealed funnel lid, the removable insert, composed of a RhinoGear™ (RhinoGear, Painesville, OH) large funnel, cut to the base of the funnel cone, with two 3" brass mesh soil sieves (both No. 18, 1 mm) attached, was used to capture sediment and filter water.

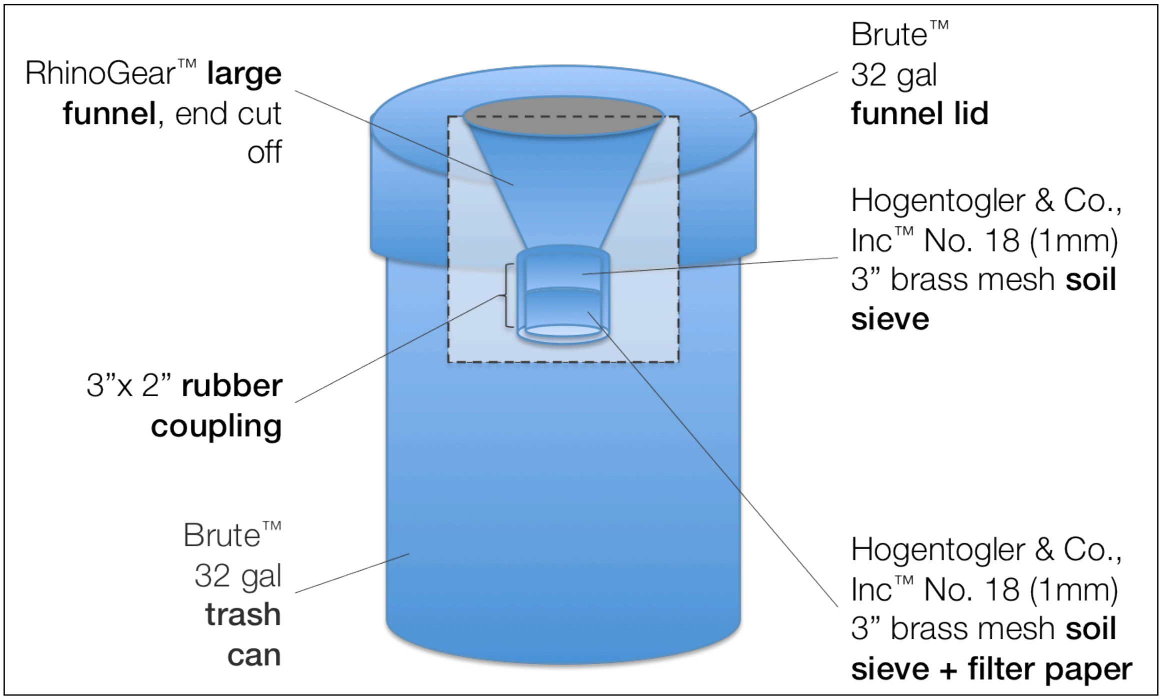

Figure 7. Diagram of sampling apparatus (not drawn to scale).

The two sieves used to filter the sediment from water were held together with a 3" x 2" rubber coupling permanently fastened to the bottom (small opening) of the large funnel using water-resistant Gorilla™ (Gannett Company, Cincinnatti, OH) glue adhesive. The rubber coupling fit snugly over the two sieves holding them in place during rain events, then it opened to allow removal of the sieve. Whatman™ filter paper (GE Healthcare, Maidstone, Kent, UK; 11µ, 70 mm diameter) was placed inside the bottom sieve to catch silt that traveled with the stormwater runoff. At each sampling event, the old filter paper was collected and dried, and the new filter paper was positioned between the two soil sieves.

To help direct the water into the sampling apparatus, a 3 m (10 ft) elongated U-shaped edging with an expanded opening at the top of the U made of Master Mark

Plastics™ 5" terrace board edging was positioned directly behind the funnel lid (Figure 8). To facilitate smooth deposition into the sampling apparatus, 3 mm Husky™ Heavy Duty Contractor Clean-up bags were placed between the vegetation and the sampling trap (front-to-back) and between the U-shaped edging (side-to-side). The plastic was covered with a mud and soil mixture, folded over, and then packed tightly to help secure it in place.

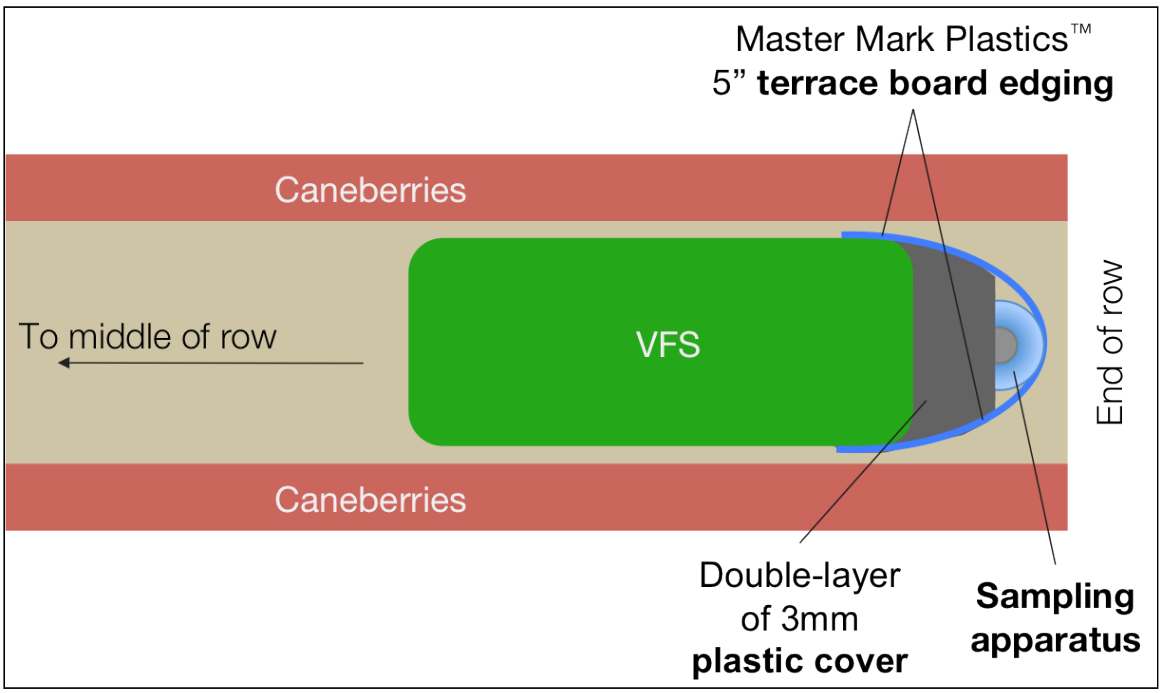

Figure 8. Diagram of VFS placement in row (not drawn to scale).

Data Collection

Vegetation

Vegetation was measured in September 2012, and then again monthly, or more often, from November through April 2013. A single researcher assigned a *Vegetation*

Quality Score (VQS), a continuous scale from 1 (worst) to 5 (best), for each plot. VQS was determined by vegetation height (relative to maximum expected height of species), vigor, and percent ground cover (Table 1). The VQS was specifically designed for this experiment and developed to determine relative growth across all treatments; it was not intended as an absolute scale that could be applied elsewhere.

Table 1. Breakdown of Vegetation Quality Score (VQS) ratings and descriptions.

RATING	DESCRIPTION		
	Relative height (*h*)	**Vigor**	**Percent ground cover (*g*)**
0	No visible growth (0%)	--	No cover; bare (0%)
(0,1]	$0\% < h \leq 20\%$	Not able to withstand minimal farm disturbances, such as light foot traffic and strong rains	$0\% < g \leq 20\%$
(1,2]	$20\% < h \leq 40\%$	Able to withstand minimal disturbances, such as light foot traffic and strong rains	$20\% < g \leq 40\%$
(2,3]	$40\% < h \leq 60\%$	Able to withstand average farm disturbances, such as medium foot traffic and strong rains	$40\% < g \leq 60\%$
(3,4]	$60\% < h \leq 80\%$	Able to withstand average farm disturbances, such as medium foot traffic, strong rains, and occasional light machinery	$60\% < g \leq 80\%$
(4,5]	$80\% < h \leq 100\%$	Able to withstand heavy farm disturbances, such as heavy foot traffic, strong rains, occasional light machinery, heavy machinery 2x-4x per season	$80\% < g \leq 100\%$

Nutrient and sediment sampling

Nutrient samples were gathered as quickly as possible after the first rain event, and always within 12 hours or less. Stormwater samples were pumped from the apparatus using a Rule™ (Miami, FL) Portable Hand Pump into an 8 oz plastic sterile bottle supplied from the testing facility. Samples were gathered within 4 hours of each other. In order to obtain the sample, stormwater in the sampling apparatus was briefly stirred with the hand pump. To eliminate possible cross-contamination between sampling sites, the hand pump was fully flushed with distilled water before the next sample was taken. Samples were carefully labeled and immediately placed in an ice-filled cooler to maintain a water temperature below 4 ºC (39 ºF) due to the volatility of nitrate. After all samples were gathered at field site, the samples were immediately driven to TestAmerica Laboratories in Pleasanton, CA.

Nitrate as nitrogen, or nitrate-nitrogen, concentrations in samples were obtained from 18 sampling apparatuses on 08 Feb 2013. Due to the accidental disking of rows on 11 Feb 2013 rendering vegetation and traps damaged beyond repair, sampling according to the original research design was no longer possible. After 11 Feb 2013, there were four additional sampling dates: 20 Feb 2013, 06 Mar 2013, 01 Apr 2013, and 04 Apr 2013, where 11 samples were collected and tested for orthophosphate and nitrate-nitrogen.

Data Analysis

Treatment effect and vegetation cover were evaluated by the amount of nitrate runoff and vegetation quality. Nitrate runoff was analyzed statistically for 8 February 2013, the only date that yielded enough samples to justify statistical analysis, a total of 18 samples. VFS vegetation quality on nitrate runoff for this date was evaluated using linear regression (n=18). In addition, effects of vegetation treatments on nitrate runoff concentrations were also assessed between subjects for repeated measures (4 treatments, n=3). Lastly, vegetation quality, as measured by the VQS scale, was analyzed using repeated measures and ANOVA across five sample dates using only the 11 plots that grew the entire season (*n*=11).

All data were analyzed using SYSTAT 13.1, and results were graphed using Microsoft Excel 2008. Nitrate and orthophosphate levels in sampled runoff on later dates were assessed qualitatively due to low sample size and replication following loss of treatments rows.

RESULTS

Nitrates

Both vegetation growth and amounts of surface runoff varied substantially across all the rows due to weather and field management practices; effects of vegetative cover on nitrates in runoff water were thus expected to be largely undetectable. Nonetheless, the highest level of dissolved nitrate was found in stormwater runoff from the row with the poorest vegetation cover, and the caneberry rows with the strong VFS growth showed significantly lower levels of dissolved nitrate runoff than the poor-vegetation rows, as of 8 February 2013 (Figure 9; linear regression R^2=0.41, n=18, p=0.004). Furthermore, an average of 50% more dissolved nitrate was detected in runoff from unplanted control plots as compared to any of the three vegetated treatments (Figure 10, *B. juncea:* n=2, *C. praegracilis*: n=3, *L. triticoides*: n=3, Control: n=3; $F(1,16)=6.771$ $p<0.019$). Nitrate levels in runoff did not differ detectably among VFS of different plant species, however, as of that date.

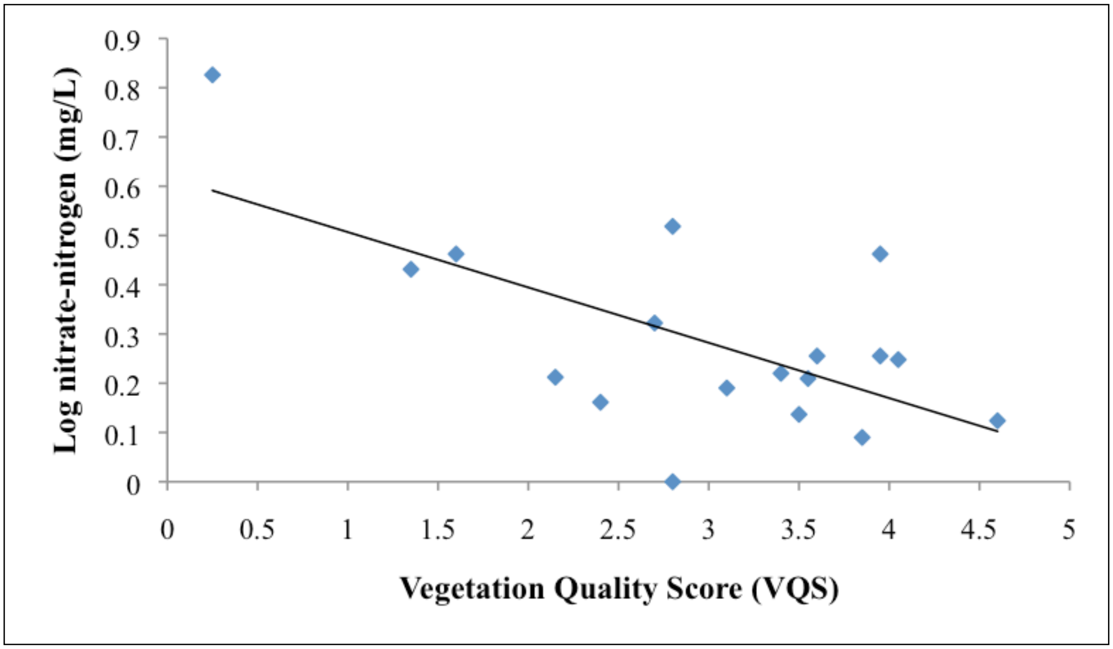

Figure 9. Amount of nitrate-nitrogen detected in sampled runoff, 08 Feb 2013.

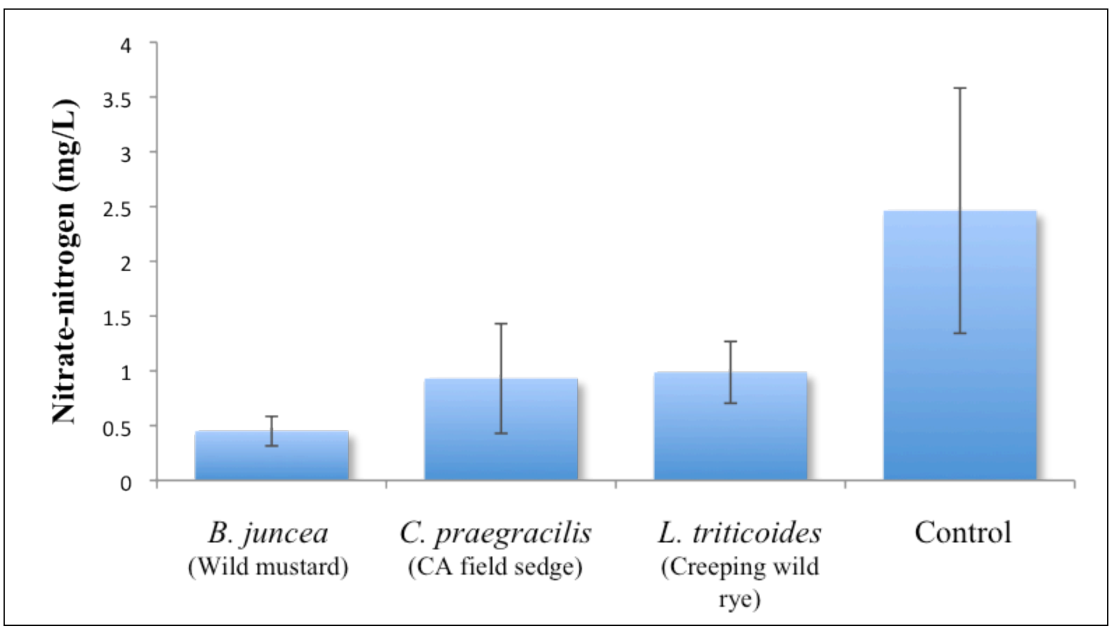

Figure 10. Amount of nitrate-nitrogen detected in sampled runoff grouped by vegetation, 08 Feb 2013.

Vegetation Quality

Among the three vegetation species tested, the wild rye (*L. triticoides*) grew most rapidly at the onset, and maintained the highest vegetation quality score throughout the trial. The native field sedge (*C. praegracilis*) grew significantly less vigorously in caneberry rows than the other two vegetation species, despite the fact that the sedge had been planted with stronger plugs. The wild mustard (*B. juncea*) effectively caught up with the wild rye by the spring sample dates (Figure 11; $F(3,28)=14.725$, $p=0.002$).

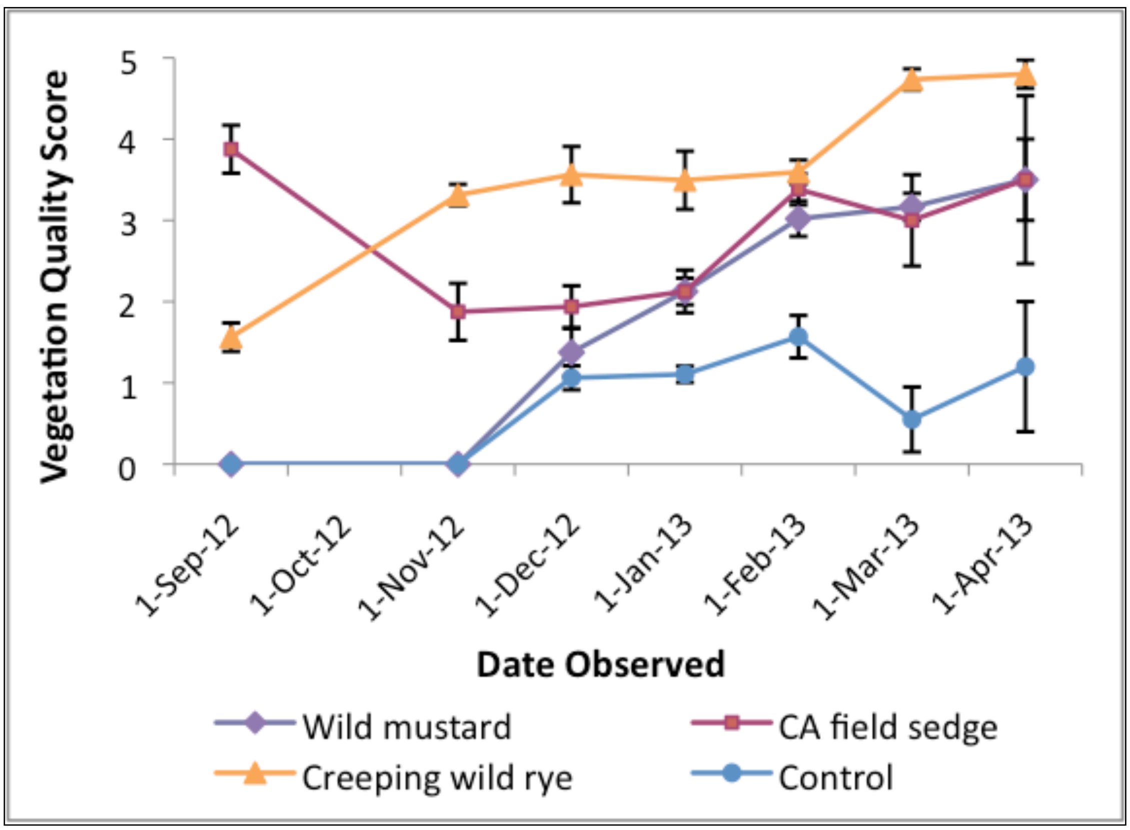

Figure 11. Vegetation quality graphed over time.

Phosphates

Despite the fact that trap and treatment damage due to tractor cultivation error in mid-February limited statistical power of phosphate runoff, February and March data indicated a possible negative correlation between orthophosphate and vegetation cover (Figure 12; linear regression R^2=0.210, $F(1,9)$=2.396, p=0.156). Further research would be needed to obtain sufficient data to assess statistical significance.

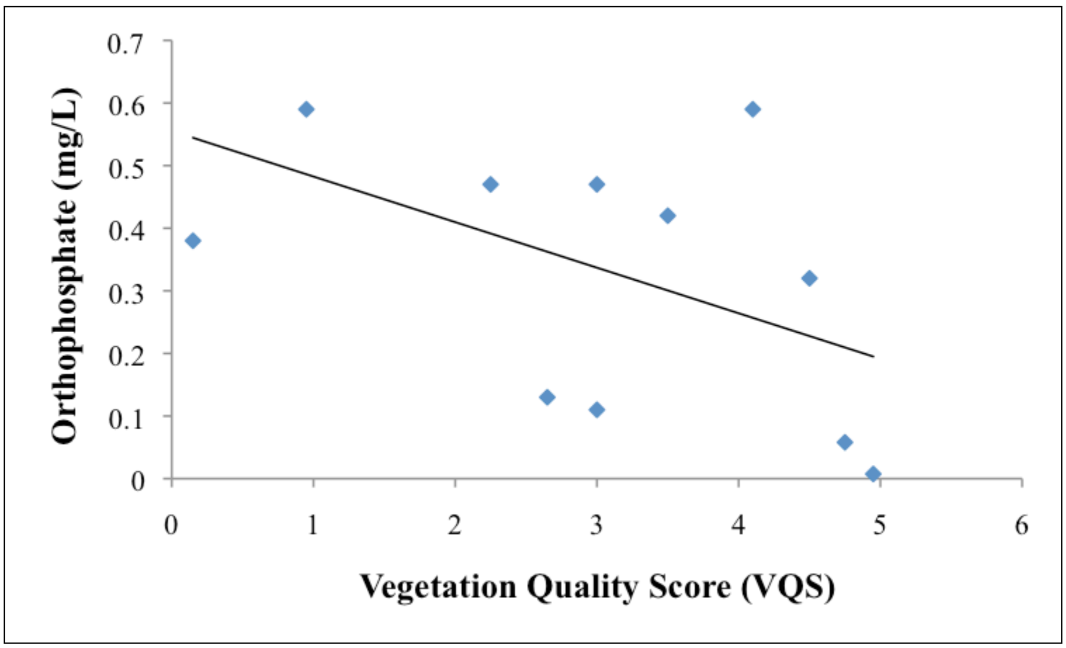

Figure 12. Amount of orthophosphate found in sampled runoff, 20 Feb 2013.

VFS Cost Analysis

VFS costs from the experimental research, including seeds or plugs and labor expenses, such as planting, irrigation, or mowing showed the price of VFS installation and maintenance to be low in comparison with overall cost of production and value of caneberries (Table 2). The costs for the two most effective types of vegetation, *L. triticoides* and *B. juncea*, when broadcast seeded range between $7.32 – $7.64 per row per year. There is approximately a five-fold difference between broadcast seed and planting vegetation as plugs. When compared to the average net cost of caneberries per row per year of $900 – $1800 (Bolda *et al*. 2012), installation of VFS using broadcast seed is 0.4 % – 0.8% of the net production cost.

Table 2. Incurred VFS costs during research.

	L. triticoides (Creeping wild rye)		*C. praegracilis* (CA field sedge)	*B. juncea* (Wild mustard)
Seeds (broadcast)	$0.47	--	$0.79	--
Plugs	--	$19.96	--	$29.35
Labor @ $15/hr	--	--	--	--
Planting	$3.10	$15.00	$3.10	$15.00
Mowing	$0.75	$0.85	$0.75	$0.85
Irrigation	$3.00	$3.00	$3.00	$3.00
TOTAL	**$7.32**	**$38.71**	**$7.64**	**$48.20**

DISCUSSION

Overall, the three species of vegetation grew successfully in the rows, and no damage was observed to adjacent berries. The sampling apparatus proved to be effective for collection of runoff water, and the design challenges due in part to unseasonably heavy early rains were broadly resolved for sediment filters over the course of the season. With the time-intensive sampling apparatus design already developed and tested in this study, any future studies can use this design and quickly propel to the installation stage, allowing for more time and focus to be spent on sampling runoff.

Nitrate results were limited to only one sampling event occurring after a light rainfall. The mild storm event did not produce enough water to gather samples from all of the rows resulting in only 18 samples from the 31 experimental rows. Moreover, nutrient concentration may have been harder to detect because the samples were taken in early February, which is a particularly low nutrient runoff period. This is because the farm has not been operating since early December, so much of the nutrients have been washed away in the previous two months of rain, and the farm will not begin spring operations until late February, so there is no runoff from new fertilizer application. Remarkably, even with the undesirable conditions and sparse data, statistically significant results were found. Since available data from this study are based on such a small sample size, the results are not conclusive, but instead indicate the need for follow-up research. This experiment serves as an important initial study helping to steer future research in a successful direction.

In this experiment nutrient concentrations were attained from runoff samples; however, determining the total amount of nutrients captured was difficult. Testing sediment samples, as well as runoff samples, for nutrient concentrations would help to provide more accurate results. The removable inset in the sampling apparatus was designed to both filter runoff as it is corralled into the basin, and capture sediment for sampling. These sediment samples would then be weighed and tested for nutrients, especially for electromagnetic orthophosphate ions that bond with the positively charged soil particles.

Perhaps most importantly for a more accurate representation of nutrient concentration is a much larger sample size, as well as many more sample events. Sample events would ideally range throughout the rainy season as levels of nutrients in runoff fluctuate and as vegetation establishes larger root systems. Larger sample sizes would illustrate a more complete picture and allow for more conclusive recommendations.

Vegetation Growth

Summary

Vegetation growth proved to be an important factor in determining the success of the vegetative filter strips (VFS). To determine the strongest type of vegetation, the VQS was used to evaluate vegetation height (relative to maximum expected height of species), vigor, and percent ground cover. Since nitrate levels varied so greatly with vegetation species and growth quality, it is likely that selecting a strong type of vegetation may be the best indicator of nutrient removal.

Plugs for *L. triticoides* and *C. praegracilis* were planted in June 2012. *C. praegracilis* plugs were sturdy and viable, and *L. triticoides* were brown and sparse. Due to its quick and hardy growth, *L. triticoides* surpassed *C. praegracilis* in VQS rating in less than two months. The thriving *L. triticoides* filled in the gaps between initial plugs and several treatments plots achieved a VQS of 4.75-4.92 by late winter. In contrast, *C. praegracilis* plugs reflected growth in height but little change in ground cover reflecting the initial clumped structure, registering VQS ratings of 2.35-4.5.

B. juncea was broadcast seeded in late October. Growth was evident by November, and by the end of the year, *B. juncea* had become well established. *B. juncea* only grew toward the center of the furrow, leaving the edges primarily void of intended vegetation. The uneven spreading of seeds when planting, or perhaps machinery passing through rows early in the growth cycle could have caused these effects. The bare sides prevented *B. juncea* from achieving VQS, ranging from 3.0-3.9 in late winter that reflected the prominence of its growth where it was seeded. For this reason, *B. juncea* may have shown stronger growth than *C. praegracilis*, although the VQS are similar in the last months of the experiment with VQS ratings of 4.05-4.95.

Perhaps even more critical than the characteristic of fast growth is the overall hardiness of the vegetation since it is virtually impossible to provide uninterrupted growth in an operating farm environment. *L. triticoides* handled disturbances, such as foot traffic and light machinery, much better than *C. praegracilis.* This characteristic was taken in account in the VQS category for *vigor*, and reflected in the VQS ratings for each vegetation type in addition to relative height and percent ground cover.

During the initial winter months, tunnels were removed, rain was plentiful, and the farm was vacated allowing vegetation to grow without human-induced disturbances. Weed growth in control plots resulting in a higher VQS than bare soil was predicted, but the control plots still earned a higher VQS than expected. This observation was assumed to be from large amounts of woody debris left in plots. When the farm workers returned in early-February, caneberry plants were trimmed leaving woody debris and foliage on the control plots until their removal several weeks later. In an effort to respect the experiment, farm workers deposited branches only on rows without vegetation. As a result, it is possible that the control plots removed more nutrients from runoff than they would under normal conditions because of the increased surface roughness. In mid-February, woody debris was removed before rows were disked.

In the early spring months, warm temperatures and ranch irrigation allowed vegetation to flourish, despite the driest recorded year in California history. *B. juncea* began bolting in mid-March, which may have occurred earlier than normal due to the above-average temperatures. With the end of the rainy season, the experiment terminated on 15 April 2013, and vegetation was removed after a period of spring growth that reflected more growth than the fall months.

Barriers to VFS Implementation

Economics

The largest barrier to widespread adoption is the cost of VFS in the highly competitive farming industry (Tourte *et al*. 2003). Although the cost of VFS is considerably less than most types of conservation buffers, there is some direct cost in establishing VFS. In addition, maintenance, such as weed control, sediment removal, and mowing, also translate to costs. Although the instances are very low, VFS may have the potential to reduce crop yield if they attract pests (Lovell and Sullivan 2006).

Agricultural programs have a large impact in adoption rates of new practices (Lant *et al.* 2001). Key factors that help determine participation include land values, crop prices, and rental rates, as well as regulatory incentives and penalties. In 2007, the USDA-NRCS's CRP program conservatively estimated benefits of $1.3 billion per year, excluding carbon sequestration, ecosystem protection, and other less easily quantified benefits. Despite these benefits, the 2008 Farm Act reduced the CRP's maximum land enrollment to 32 million acres, a 9% decrease from 2007. Furthermore, increases in crop prices since 2006 may discourage landowners from converting productive land to conservation buffer zones (Ribuado *et al.* 2010).

A commonly criticized provision of the CRP is the emphasis on development of new VFS rather than the preservation of existing lands. Economic rewards incentivize destroying lands and building compliant buffers instead of maintaining existing natural riparian buffers or wetlands that often provide greater environmental benefit, including plant and animal biodiversity (Lowrance and Crow 2002).

Land ownership may be another obstacle to the adoption of VFS (Lovell and Sullivan 2006). The vast majority of the area around streams and rivers is privately owned. As a result, it is strictly the landowner's decision to implement VFS. There are new ideas to challenge this old system by using public trusts or non-profit organizations can buy the land in sensitive areas to allow for the establishment of buffers and corridors that benefit the community; however they are still being developed (Ribuado *et al.* 2010).

The lack of widespread agricultural VFS implementation and heavy reliance on incentive programs suggests the costs still outweigh the advantages of VFS. Previous economic incentive programs have not been sufficient to stimulate use of VFS (Ribuado *et al.* 2010), however the effect of the current CCRWQCB *Waiver No. R3-2012-0011* is yet to be determined.

Performance

Declines in VFS effectiveness have been observed several years after implementation by researchers (Borin *et al.* 2005). It is likely that this loss of ability is related to a lack of proper maintenance for VFS (Dabney *et al.* 2006; Grismer *et al.* 2006). For example, small channels will form in fields that will decrease the effectiveness of VFS (Dabney *et al.* 2006). No-till fields will result in ephemeral gullies likely to form in the same place year and year. In tilled fields, tillage-induced berms, small channels formed from tillage parallel to contour buffers and perpendicular to waterways, are inevitable after a period of time. These berms will cause runoff to flow parallel to VFS. This may be avoided with maintenance, but it is not commonly practiced. Perhaps the lack of maintenance is not simply economical, but may also be attributed to the lack of easily accessible information. There is an abundance of information regarding VFS implementation, but little information is circulated on how to manage VFS once they are in place (Lovell and Sullivan 2006).

Decreased effectiveness is especially prevalent in removal rates of P (Stutter *et al.* 2009). This is likely due to poor maintenance and saturation. On one hand, Stutter *et al.* (2009) discuss the "predictable lifespan" of VFS as they become P-saturated and lose P-buffering efficiency (Stutter *et al.* 2009, 1858) and Kim *et al.* (2006) document minimal P removal in saturated flow paths of VFS. On the other hand, Both Stutter *et al.* (2009) and Kim *et al.* (2006) state that with a better understanding of the preferential flow principles, it is likely the interactions of VFS and P cycling could provide opportunities for better management of P retention or removal. Kim *et al.* (2006) believe the results show the importance of maintenance to assure uniform distribution and infiltration of runoff within the VFS.

Aesthetics

The aesthetic perception of VFS on farms and ranches has been found to be a greater implementation barrier than initially thought (Lovell and Sullivan 2006). The manicured, predictable setting propagated by monoculture farms has become the industry standard and many stakeholders equate the landscape to neatness and care (Ryan 1998). Contrastingly, small-scale farmers tend to exhibit a preference for a more natural farm setting and feel that it still conveys a sense of hard work (Lovell and Sullivan 2006). It is likely that the general trend has shifted toward pleasing consumers and stakeholders in light of the recent food safety concerns.

Compliance with CCRWQCB *Waiver No. R3-2012-0011*

In 2012, the State of California commissioned researchers from the University of California at Davis to investigate the extent of nitrate contamination in California's drinking water. In their report, *Addressing Nitrate in California's Drinking Water*, Harter *et al.* (2012) concluded nitrate pollution in groundwater and drinking water in the Central Coast region is a critical problem. The report points to agricultural irrigated lands and the primary source of nitrate contamination to these groundwater aquifers and wells (Harter *et al*. 2012). As a result, the State of California water regulators appear to be taking a no-nonsense approach to protecting California's critical water supply. Agricultural lands are categorized into one of three tiers using several criteria, such as farm size, type of pesticides used, and amount of waste discharge. Each tier has its own set of rules and regulations, but all tiers mandate nitrate testing and restrict the amount of nitrate waste discharge. Violators will be fined for exceeding discharge amounts.

The CCRWQCB *Waiver No. R3-2012-0011* states all agricultural lands "must implement quality protective management practices (e.g., source control or treatment) to prevent erosion, reduce stormwater runoff quantity and velocity, and hold fine particles in place" (Appendix A, 20). Dischargers must also "minimize the presence of bare soil vulnerable to erosion and soil runoff to surface waters and implement erosion control, sediment, and stormwater management practices in non-cropped areas, such as unpaved roads and other heavy use areas" (Appendix A, 37). In addition to penalizing violations, the current Agricultural Waiver offers additional incentive for compliance; for example, it is stated that: "The Central Coast Water Board recognizes efforts to maximize water quality improvement using innovative and effective local or regional treatment strategies and it is the Central Coast Water Board's intent to provide flexibility in the implementation of the order to encourage discharger participation in such efforts…" (Appendix A, 118).

VFS implementation is likely to be considered an innovative and effective local or regional treatment, and therefore may be well worth the grower's effort because lenience will be granted for nitrate discharge. The relatively low cost and demonstrated nitrate reduction benefit suggest that VFS could be a cost-effective tool that growers can use to help reduce nitrogen runoff in caneberry fields in the Central Coast of California. Costs are estimated to be $300-$900 per acre for monitoring, controlling, and enacting *CCRWQCB Waiver No. R3-2012-0011* (CCRWQCB 2012).

Conclusions

In all plots, bare soil, or the control, had higher nitrate runoff concentrations. Even when weeds grew on the bare soil to provide minimal cover during winter months, the control still showed higher nitrate concentrations. As a result, any treatment was recommended over bare soil.

The native field sedge, *Carex praegracilis,* grew significantly less vigorously in caneberry rows than other species tested; however, *C. praegracilis* showed significant nitrate removal in this study, as well as both nitrate and pathogen removal in previous studies (Bratieres *et al.* 2008; Karlik *et al.* 2009; Palmer 2012). A large advantage to the sedge is the lower, denser vegetation that results in higher percent of ground cover promoting more nitrate removal and discouraging runoff berms that may occur with higher vegetation (Palmer 2012). As a California native, *C. praegracilis*, has many other environmental benefits for a farm, but since the plugs were expensive and vegetation was difficult to establish over one season (Figure 13), *C. praegracilis* is recommended for a more permanent location in edge-of-field VFS.

Figure 13. California field sedge (*C. praegracilis*) in June 2012 (left) and April 2013 (right)

Widely available and inexpensive, *B. juncea* grew well from broadcast seed and tolerated trampling well also. *B. juncea* is planted later in the season so it is not helpful for fall cover, but once it is established, it grows quickly and vigorously (Figure 14). This species produces bright yellow flowers that may serve as habitat for insect predators (Ahuia *et al.* 2010; Hooks and Johnson 2003), as well as providing aesthetic value. Furthermore, *B. juncea* has been suggested as helping with root pathogen control (Niorge *et al*. 2007; Shennan *et al.* 2007; White and Brown 2010) that may be highly attractive to growers working to comply with current food safety standards. *B. juncea* has a long taproot to potentially extract deeper nitrate-contaminated runoff in the root zone (Salido *et al*. 2003) but the same property may also provide decreased surface roughness because of the less dense root structure. For all these reasons, *B. juncea* is recommended for in-field VFS.

Figure 14. Wild mustard (*B. juncea*) in January 2013 (left) and April 2013 (right).

The VQS scores showed that *L. triticoides* grew most effectively while demonstrating significant nitrate removal, as supported by previous studies (Grossman and Brown 2007; Moore *et al.* 2011; Powers 2006). This versatile plant type can be planted as plugs or broadcast seeded. While requiring little irrigation, the rye grew quickly to produce fall cover in rows and maintained its vigor throughout winter and tolerated trampling well (Figure 15). *L. triticoides* is also a native to California and may provide other environmental benefits (Comer *et al.* 2006; Gorham *et al*. 1984), including resistance to disease (Hu *et al.* 2002; Yang *et al.* 2008) and its ability to outcompete non-native species (Lulow 2006). Furthermore, *L. triticoides* provides good middle ground between the less dense longer taproot of the *B. juncea* and the denser, shallower root system of *C. praegracilis.* As a result, *L. triticoides* is recommended for in-field VFS.

Figure 15. Creeping wild rye (*L. triticoides*) in June 2013 (left) and April 2013 (right).

Recommendations

Although any vegetation proved better than bare soil, VFS with higher VQS ratings reduced more nitrate from farm runoff. *L. triticoides* and *B. juncea* had high VQS ratings and can be broadcast seeded, which offers a low cost alternative to plugs. A combination of *L. triticoides* and *B. juncea* together is recommended for a complementary VFS planting mix for fall and spring cover.

In-field VFS as short as 6.1 m (20 ft) and approximately 1.2-1.5 m (4-5 ft) at the end of the rows were able to significantly reduce nitrate runoff. This recommendation is supported by some research (Balestrini *et al.* 2011; Borin *et al.* 2005; Dillaha *et al.* 1989; Parsons *et al.* 1991; Schmitt *et al.* 1999), but the vast majority of literature suggests VFS must be at least 10 m (Abu-Zreig *et al.* 2004; Castelle *et al.* 1994; Lee *et al.* 2003; Magette *et al.* 1989; Stutter *et al.* 2009; Vought *et al.* 1995). Shorter VFS are easier to install and manage, and provide a more cost-effective solution for managing nitrate discharge.

To effectively reduce nitrogen runoff in caneberry fields in the Pajaro Valley, this study demonstrated that vegetative filter strips (VFS) planted in late summer to early fall can easily and inexpensively be maintained between rows. In-field VFS in anchor rows do not conflict with in-row management activities. VFS can be used as a cost-effective way to reduce nutrient levels in runoff in compliance with the *CCRWQCB Waiver No. R3-2012-0011*.

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