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Still Searching: research and extension in California organic no till vegetable production

Author

Wong, Darryl G

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STILL SEARCHING: Research and extension in California organic no till vegetable production

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By

Darryl G. Wong

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The Dissertation of Darryl Wong is
approved:

Professor Carol Shennan, chair

Professor Daniel Press

Professor Weixin Cheng

Peter Biehl
Vice Provost and Dean of Graduate Studies

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ABSTRACT

STILL SEARCHING: Organic no till vegetables in California

Darryl G. Wong

As climate change presents more and varied challenges for food production there is a need for novel systems that can balance social and ecological outcomes. No till practices have shown incredible promise providing important ecological benefits, but these systems are still heavily reliant on chemical herbicides and fertilizers and have been limited in adoption to major commodity crops in humid regions without water limitations. Organic agriculture has proven to be a viable production system across a wide range of crops while excluding synthetic pesticides and chemicals that create downstream effects for human and non-human communities. There has been little success in developing the "holy-grail" of organic no-till farming especially for nutritionally important vegetable crop systems in California. I explore the history of organic no till research (Chapter 1), highlighting specific challenges and opportunities from regional syntheses of organic no till production in commodity crops as well as the slowly growing body of literature on organic no-till vegetable production. I then review the results of a 3-year field trial exploring a novel low-reside organic no till production system on yield and nutrient dynamics (Chapter 2). Finally, I explore the cooperative extension service (Chapter 3) and discuss why it has failed to support ecological innovations given its contested history. This work argues that while research on organic no till systems is still at a nascent stage, there are a number of meaningful research pathways to pursue: 1) a focus on basic agronomic challenges, 2)

suitability of cover crops and specific cash crop/cover crop combinations, and 3) long-term studies without cash crops to assesses soil physical and chemical properties. Further, given the nature of highly commodified California vegetables, cooperative extension, despite its inconsistent track record, has an important role to play in supporting newer models of social learning, adaptive research and university/grower partnerships that are needed to support this and future endeavors.

DEDICATION

To the soil that holds us, feeds us, and to which we will return.

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I have never been a typical graduate student. I dropped out of college in my early twenties and returned to finish my undergraduate degree only after I had been farming for five years. Completing this dissertation, was never going to be possible without a community of support. First and foremost, my beautiful family, Amy, Leila and Winston, have provided consistent joy and respite from hours of research and always called me to the bigger picture. My advisor, Daniel Press, played a particularly pivotal role in this process, first hiring me into UCSC, sponsoring my graduate application, serving as my "double-boss" and providing endless academic support. However, more than the academic and professional support, Daniel held me as a whole person and consistently helped to balance competing tensions of work, school, and life. My farming partner, Kirstin Yogg, has worked loyally with me through nearly 2 decades of farming, and has always provided inspiration, collaboration, laughter, and camaraderie in what can be a particularly lonely field. Last, my farming mentor, Jim Leap, who got me hooked on farming from the first weld and has never creased to inspire me with his passion and dedication to the craft and community.

INTRODUCTION

As climate change continues to present major challenges for agriculture in the coming decades there is more need than ever for novel agricultural solutions that address key social, environmental and economic issues. No till (NT) practices have been implemented on millions of hectares worldwide (Kassam et al., 2019) addressing historic agricultural issue of top soil erosion, water infiltration and diversification (Derpsch et al., 2010). However, these systems still present considerable environmental challenges as they rely heavily on herbicides and chemical fertilizers that are prone to off farm contamination and leaching. Organic systems have been able to exclude these products with mature systems that provide considerable co-benefits (Shennan et al., 2017). However, the "'holy-grail' of organic no till farming" (Lehnhoff et al., 2017) has been slow develop with both adoption (Derpsch et al., 2010) and research (Vincent-Caboud et al., 2019) lagging far behind conventional systems in the United States.

Research into organic NT (OGNT) systems has been primarily focused on commodity crops (corn, soy, wheat) with research concentrated in North America and Europe. While some success has been found with soy, experiments employing corn and wheat rotations have been less successful, hinging largely on challenges with cover crops grown as *in-situ* for mulch. In OGNT systems, these cover crops need to produce enough biomass with the right C:N ratios to balance weed suppression (high C:N ratio) and nutrient provisioning (low C:N ratio). Cereal rye and vetch most closely approximate this balance, however, the biological delays in termination timing cascade into additional grower challenges including: delayed planting, shorter growing seasons, inadequate nutrient cycling, and decreased in-season water availability in arid climates. Variability in cover crop production based on field heterogeneity and annual climactic variation, combined with few field-tested mechanical solutions to weed control and nutrient management, limit system flexibility and have hampered adoption.

OGNT research on vegetables has been much slower to materialize, though there has been an increase in published studies in the last ten years. OGNT vegetables have suffered many of the same issues as OGNT commodity crops, primarily with cover crop selection and the lack of options to address inherent variability present in organic vegetable systems. Tomatoes and cabbages have shown the most consistent promise in these systems across regions. Results in other crops have been largely mixed with some success found by integrating plasticulture and NT practices with a combination of legume cover crops and heavy supplemental fertilization. For many crops OGNT vegetable studies fail to compare experimental yield data against standard regional production expectations, diminishing the value of experimental yield equivalencies. Variable yields and near complete crop failures in many trails is indicative of the immaturity of these systems. OGNT vegetable production presents additional challenges due to the prevalence of high economic return crops, especially in water limited environments of the arid west. As such there have been virtually no studies of OGNT vegetable production systems in California. For such a novel and paradigm shifting system, future research should include parallel tracks including: 1) a focus on basic agronomic challenges (i.e. planting, seeding, high residue cultivation, fertility application and selection), 2) suitability of cover crops and specific cash crop/cover crop combinations, and 3) long-term studies assessing the potential of OGNT systems to improve soil physical and chemical properties.

CHAPTER 1

ORGANIC NO-TILL VEGETABLES

No till Agriculture Today

Agriculture today faces enormous challenges on a global scale. While productivity gains over the past 100 years have led to exponential growth in yield and efficiency, these gains have come at serious environmental costs. Agriculture utilizes 40% of all arable land on the planet and conventional practices have been identified as major drivers of climate change, biodiversity loss, fresh water use and pollution, and soil degradation (Foley et al., 2005; Foley et al., 2011). Pockets of intensive agriculture across the globe are in danger of pushing global nitrogen and phosphorous cycles beyond planetary boundaries (Steffen et al., 2015).And of course, all of this is occurring within the context of a growing population with increasing numbers of poor and hungry; a fact that continues to drive a narrative of the need for increased agricultural production (Conway and Simmonds, 1998; Foley et al., 2005).

While a diversity of fields and approaches have responded to these challenges, including integrated pest management, organic agriculture, sustainable farming, precision agriculture and regenerative agriculture among them, far and away the most popular response in recent decades has been no-till (NT) agriculture. From 2.8 million hectares (ha) in NT production in 1974, the number has grown to over 111 million ha today (Derpsch et al., 2010). No- till systems are captured under the umbrella term Conservation Agriculture, which the Food and Agriculture Organization defines as 1) continuous minimum mechanical soil disturbance, 2) permanent organic soil cover, and 3) diversification of crop species grown in sequences and/or associations (Fao, 2014). This definition was left intentionally vague around specific measurements or techniques so as to achieve the greatest global applicability within local contexts. However, as researchers and practitioners have attempted to better understand these systems, many have looked toward the straightforward definition of Phillips and Young to more clearly define the requirements of a NT system: “no-tillage is defined as a system of planting (seeding) crops into untilled soil by opening a narrow slot, trench or band only of sufficient width and depth to obtain proper seed coverage. No other soil tillage is done” (1973).

No-till systems have developed on the premise that producing crops, while maintaining continuous soil cover without tillage, more closely mimics and retains a soil’s original desirable characteristics (Derpsch et al., 2010). Soil quality is often dictated by the quantity and quality of soil organic matter (SOM) due to its central role in key soil functions (Carter, 2002). In NT systems, SOM is increased through the frequent application of organic mulches and simultaneous breakdown of root biomass. Meanwhile, the elimination of tillage passes that stimulate microbial breakdown and oxidation of existing pools of SOM through increased soil temperatures, oxygen and water, can further increase SOM levels. As soil quality improves via an increase in SOM, a host of secondary benefits arise, including better aggregation, increased aeration, increased soil nitrogen, preservation of soil structure, preservation of earthworms and soil fauna, improved infiltration, soil moisture conservation and water holding capacity, moderating soil temperatures, reduced germination of weeds, natural mixing of soil potassium and phosphorus and improved drainage. These increases in soil quality, in combination with the elimination of tractor passes, in turn, can decrease soil erosion and subsequent pollution of water ways (Baker et al., 2007a; Chaney and Swift, 1984; Hudson, 1994; Soane, 1990).

On an economic level, (Baker et al., 2007a) these improvements in soil quality, combined with fewer overall tractor passes, lead to significant increases in profitability. Improved soil quality reduces input costs for both herbicides and fertilizers, while the elimination of tractor passes decreases overall labor, machinery and fuel costs. Conventional tillage systems often require 15-18 tractor passes per season, whereas NT systems can require as little as 2-3 passes (Mitchell et al., 2006). Increased water holding capacity decreases irrigation requirements and associated energy costs (Baker et al., 2007a) It is difficult to broadly and accurately classify overall costs reductions and profit increases because of significant variability in cropping systems, soils, and climates, but ample studies identify the success of NT systems in meeting or exceeding conventional tillage yields (Soane et al., 2012)while demonstrating significant cost savings per ha (Baker et al., 2007a)

Beyond the ecological and economic successes, NT systems have attracted the greatest attention recently as a climate change mitigation strategy due their potential to decrease agricultural greenhouse emissions as well as to sequester carbon in the soil. Research estimates that agriculture and land use change is responsible for 20% of global CO2 emissions (IPCC, 2001). On the farm level, looking at, both primary (tillage, irrigation, sowing, spraying, harvesting, and transport) and secondary sources (fertilizer and pesticide production, soil erosion and SOC mineralization), NT systems have the potential to reduce CO2 emissions by up to 84% (Lal, 2004a)

Soil carbon sequestration is also a promising mitigation strategy for global CO2. Lal published the most comprehensive and well cited (4281 citations) discussion of this potential. He promotes soil C sequestration based on the overall size of the soil C pool and the degree to which it has been degraded. The soil C pool dwarfs the other pools, at 3.3 times the atmospheric pool and 4.5 times the biotic pool, and also reflects huge potential for sequestration, as 60-75% of this pool has been degraded by agriculture and the conversion of natural ecosystems. Lal looks at the area covered and the potential carbon sequestration potential using recommended management practices on 4 agroecosystems: cropland soils (1350 Mha; 0.4 to 0.8 Gt C/yr), rangelands and grasslands (3.7 Bha; 0.01 to 0.3 Gt C/yr), degraded and desertified soils (1.1 Bha; 0.2 to 0.4 Gt C/yr), and irrigated lands 275 Mha (0.01 to 0.03 Gt C/yr). Combined, these totals could offset fossil fuel emissions by 5-15%, with cropland adaptation responsible for 65-90% of these savings despite representing 20% of the total area. This impact reflects the degree of degradation in cropland soils and the potential of NT to increase soil C (Lal, 2004b; Lal et al., 1999). Estimates by Lal were further corroborated by an analysis of 67 long- term agricultural experiments, consisting of 276 paired treatments his synergy of benefits has led to widespread adoption of NT systems worldwide. Globally, 111 million ha of land are in NT with the highest number of acres in the USA (26.5 Mha), Brazil (25.5 Mha), Argentina (19.7 Mha), and Canada (13.4 Mha).

The current success of NT systems is a direct result of technological improvements over the last century. National conversations about shifting agriculture towards crop production without tillage were recorded in the late 1930s after the “Dust Bowl” ravaged Midwest soils. After decades of intensive tillage, combined with unprecedented drought, the dust bowl saw single storms move as much as 350 million tons of soil, some traveling as far East as Buffalo, New York (Danbom, 1995). As a result, Congress authorized the creation of the Soil Conservation Service, now the National Resource Conservation Service, and Time Magazine claimed that the debate over tillage was “the hottest farming argument since the tractor first challenged the horse” (1944). Despite this robust debate, NT systems eventually lost out to conventional tillage approaches because of the inability to control weeds (Baker et al., 2007a). It was not until the development of the herbicides paraquat and diquat that “spawned the birth of true no-tillage” (ibid). Previously, residual effects of available herbicides required several weeks of plant back time due to longer lasting toxicity. These new broad spectrum, non-residual chemicals allowed almost immediate plant back timing, and have been further adapted for agricultural and home use, Round-Up being the most popular example. Research trials followed quickly in the US, UK, and Latin America (Baker et al., 2007a; Derpsch, 2008; Lal, 2007).

This reliance on herbicide use has led many to question the true sustainability of NT systems. Indeed, when inspecting global NT adoption rates from Table 2, Europe lags considerably. This has been attributed to the higher degree of herbicide regulation in the EU as compared to the US and Latin American policies (Soane et al., 2012). Furthermore, herbicide- resistant weeds are evolving rapidly in both the UK and the US, which could greatly reduce the potential for NT adoption (Davies and Finney, 2002; Soane et al., 2012; Triplett and Dick, 2008).

Additionally, Baker et. al. questioned the analysis done by West and Post on long term NT trials globally, also challenging the basis of Lal's work on global soil C sequestration. Baker et. al. cited potential sampling protocol bias as many of the long-term trials only collected SOC data down to 30 cm. When trials compared rates of C sequestration at deeper depths there was no significant difference in soil C accumulation over the trial period, only a difference in vertical distribution; NT systems tended to concentrate C at the surface, whereas tillage systems accumulated more carbon at deeper depths (Baker et al., 2007b). Olson and Al-Kaisi confirmed these findings when looking at SOC accumulation in a 20-year trial comparing NT and moldboard (MP) plow treatments. They found that SOC in the NT treatment was increased over the trial period in the 0-5 cm range, but actually decreased against the baseline in the 5-35 cm range. Additionally, the MP treatment showed higher levels of SOC accumulation in the 20-35 cm layer than the NT treatment (Olson and Al-Kaisi, 2015).

NT systems worldwide, have also expanded on major commodity crops, which differ significantly from other agricultural systems. While the commodity crops represent a majority of the agricultural products in our industrial food system, there has been less research and adoption of NT systems with nutritionally important vegetable crops (Derpsch and Friedrich, 2010).

While NT systems have provided much success, researchers and practitioners have simultaneously developed parallel systems that utilize some tillage to address some of the agronomic challenges of NT, while still generating more favorable environmental outcomes than conventional tillage systems. These systems have been captured under the broad umbrella of Conservation Tillage, defined as cultural practices for crop production that simultaneously protect and enhance soil resources (Allmaras and Dowdy, 1985). This definition includes NT systems, but also outlines other specific production systems. The Conservation Technology Information Center (CTIC) (1995) provides the most frequently cited definitions used in the US. The six bullet points below list the CTIC's other systems (reproduced verbatim from the CTIC's list):

> Conservation Tillage Types (30 percent or more crop residue left, after planting): any tillage and planting system that covers 30 percent or more of the soil surface with crop residue, after planting, to reduce soil erosion by water. Where soil erosion by wind is the primary concern, any system that maintains at least 1,000 pounds per acre of flat, small grain residue equivalent on the surface throughout the critical wind erosion period.
>
> Strip till/Zone till: A modification of NT, sometimes similar to RT. Row width disturbance of less than 25% is necessary to fulfill the surface residue coverage. This variant of no till provides for traffic control in row crops.

Ridge-till: the soil is left undisturbed from harvest to planting except for strips up to 1/3 of the row width. Planting is completed on the ridge and usually involves the removal of the top of the ridge. Planting is completed with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is accomplished with crop protection products (frequently banded) and/or cultivation. Ridges are rebuilt during row cultivation.

Mulch-till: full-width tillage involving one or more tillage trips, which disturbs all of the soil surface and is done prior to and/or during planting. Tillage tools such as chisels, field cultivators, disks, sweeps or blades are used. Weed control is accomplished with crop protection products and/or cultivation.

The CTIC also provides useful definitions of other tillage types that do not meet the 30% residue requirement:

Reduced-till (15-30% residue): full-width tillage that involves one or more tillage trips disturbing all of the soil surface and performed prior to and/or during planting. There is 15-30 percent residue cover after planting or 500 to 1,000 pounds per acre of small grain residue equivalent throughout the critical wind erosion period. Weed control is accomplished with crop protection products and/or row cultivation.

Conventional-till or intensive-till: full width tillage that disturbs all of the soil surface and is performed prior to and/or during planting. There is less than 15 percent residue cover after planting, or less than 500 pounds per acre of small grain residue equivalent throughout the critical wind erosion period. Generally involves plowing or intensive

> (numerous) tillage trips. Weed control is accomplished with crop protection products and/or row cultivation (CTIC, 1995).

With all of the CT-specific practices as well as NT systems, agronomic advantages include improved planting and harvesting timing, increased potential for double cropping, soil moisture conservation via decreased evaporation, increased infiltration, and increased water holding capacity, reduced costs (fuel, labor, machinery). CT systems that incorporate some tillage are primarily aimed at managing complications with NT, namely soil warming, weed management and plant/seed establishment. These are also the main challenges for organic and vegetable adoption in NT. As a result, these systems have been more widely adopted for organic production both in US and in Europe, but many European organic farmers are not considering the complete elimination of tillage(Carr et al., 2013; Carr et al., 2012).

Current conventional NT systems have a long history, with extensive research and adoption worldwide. These systems have shown significant gains on important ecological indicators that have eluded conventional tillage-based systems, namely soil erosion, water retention and SOM accumulation. While yields can be lower than tillage-based systems, net returns tend to exceed these systems due to decreased production expenses. However, the reliance of these systems on herbicides has exposed new challenges including herbicide resistant “super weeds” and there are questions about carbon sequestration in the absence of supplemental, and importantly more nutritionally diverse, carbon inputs more typical in organic systems. There has been little research on vegetable or organic systems, though the broad suite of conservation tillage approaches have supported these efforts.

Organic No till Research

Parallel to conventional NT efforts, there has been a focused, albeit more modest, exploration of the adaptability of these systems to organic production. NT systems have failed to take hold as strongly in organic (OG) production systems with major adoption challenges including general weed management and nutrient limitations due to the decrease in tillage-induced SOM mineralization (Peigné et al., 2007). While there has been some development of organic herbicides, they are generally cost prohibitive and ineffective. Without these tools, organic systems still rely on shallow tillage to physically kill weeds.

While research is more limited, these organic efforts have remained focused on commodity crops, specifically corn, soy and grains, with much of the publishable research focused in North America and Europe (Carr, 2017). Morse and Creamer (2006) provided early reviews of OGNT systems, with the most recent reviews by Vincent-Caboud et. al. (2019). Carr has tracked the historical development of organic no-till research (2017) and helped to organize many of the most relevant regional reviews of OGNT systems in Europe (Navarro ‐ Miró et al., 2022; Vincent-Caboud et al., 2017), Canada (Halde et al., 2017), Germany (Zikeli and Gruber, 2017), the US mid-Atlantic US (Wallace et al., 2017), the US Midwest (Silva and Delate, 2017), the US West (Luna et al., 2012), the US Northern Great Plains (Lehnhoff et al., 2017) and the US Southeast (Reberg-Horton et al., 2012). These studies are reviewed here and generally speak to the limited application and adoption of OGNT practices and highlight major focus areas: cover crop management, cash crop systems, yield outcomes, weed suppression, nutrient management, and soil health benefits.

Due to their importance for weed suppression, water retention, nutrient supply, and soil health, cover crop management continues to be a primary area of focus for OGNT systems. Management is focused on cover crop production (biomass production, varietal selection and mixtures, timing, and spatial distribution), chemical composition (C:N ratio) and cover crop termination (timing and method). While there has been experimentation with a handful of cover crops, most regions rely heavily on the use of cereal rye and vetch as mono cultures or mixtures(Vincent-Caboud et al., 2019). There are few grasses that are as suppressive as rye, as a result of allelopathy and biomass production. In the US Midwest, mid-Atlantic and Southeast, rye is the favored crop to precede soy, and where more nitrogen is needed, a mixture with vetch is preferred. While single species vetch cover crops can provide more nitrogen for higher requirement corn, they also provided less full season weed suppression due to lower C:N ratios and faster decomposition.

Generally, studies across regions continue to cite the need to produce 5-7 Mg/ha of biomass to support effective weed suppression (Teasdale and Mohler, 2000), though many of the more experienced regions (US-Midwest, southeast, mid-Atlantic) pushed for 8-9 Mg/ha. A notable exception is in systems in cooler climates that rely on winter killed cover crop termination (Ginakes and Grossman, 2021;

Lilley and Sánchez, 2016). Where biomass drives weed suppression, climate has proven to be a key factor in the success of cover crops. In the European context, Vincent-Caboud et al., (2019) suggest a trade-off between cool and humid regions that support cover crop growth and the drier and warmer southern regions with warmer general temperatures that can offset soil temperature suppression typical of NT. This is presented in opposition to the humid warm regions of the US-Midwest, southeast and mid-Atlantic, that can both support biomass production with adequate seasonal rainfall, while also maintaining higher temperatures that support economic production values. The US Northern Great Plains and the West, push the southern European dynamic further with even more water limited environments. The US Northern Great Plains has such limited and unpredictable winter rainfall that biomass thresholds for suppression may not be met. When these higher thresholds are met, they come at the expense of soil water that is typically relied on to bring crops to full maturity. This dynamic plays out in the US West as well where increased cover crop evapotranspiration depresses subsequent cash crops yield.

Independent of these climate variations, all regions expressed challenges with termination timing in organic systems. Conventional systems use herbicides to terminate cover crops during ideal planting windows, however, with organic systems, all regions expressed the challenge of delayed planting timing as a result of the biological requirements (50% rye anthesis or late flowering to early pod set for vetch) (Keene et al., 2017) for successful use of the roller crimper. In the US Midwest, mid-Atlantic, and Southeast, this delay in termination required growers to use shorter maturity varietals that reduced yields compared with longer season cultivars, impacting economic viability. These planting delays were consistently 2-3 weeks later in the West and also affected yields in tomatoes, eggplant and cotton. In addition to these delayed planting dates, incomplete termination of the cover crop continued to be a major factor in Canada, the US West, and Europe. Halde, Gagné, Charles, & Lawley (2017) acknowledged that in Canada this was often a result of growers not waiting until the biological threshold for termination, which was likely similar in the US West experiments. When vetch-rye mixtures are used in the US mid-Atlantic, growers face challenging termination asynchrony whereby rye may be ready to terminate 1-3 weeks ahead of the vetch. As a result, two rollings proved necessary with sequencing of roll-plant-roll preferred over roll-plant or roll-roll-plant. Finally, in the US Midwest there was evidence of terminated rye continuing to mature and set viable seed, which presented contamination problems in subsequent wheat rotations. In the mid-Atlantic vetch presented similar issues. Silva & Delate (2017) suggest that this may point to the relatively narrow biological window to achieve successful termination between 50% anthesis and milk stage, giving growers little flexibility in an already challenging cropping system.

Similarly, variation in cover crop stand both within and between years presented a major challenge to OGNT adoption across regions. This was highlighted in Canada where annual biomass could vary between 4-10 Mg/ha and there was considerable spatial variability of cover crop biomass within fields that created significant issues with weed management. Most regions recommended higher seeding rates for rye: 180–269 kg/ha in the Midwest, 134 kg/ha in the mid-Atlantic and 110-150 kg/ha in Canada. In the mid-Atlantic and Midwest, this emphasis on cover crop establishment led both systems to rely on "rotational" fall tillage for adequate fertilization and seed bed preparation to support cover crop stands. In the mature US OGNT systems even where stands reached sufficient biomass levels, weeds continue to be an issue late in the cropping cycle with perennial weed escape a significant and persistent problem. While cover crop mulches can control 80% of weeds in soy systems, slow canopy closure makes late season weeds problematic. The mid-Atlantic and Midwest are working towards high residue cultivation systems that would allow growers to mechanically terminate weeds approximately 2.5-5cm below the surface while leaving the mulch in place. Despite the success of these systems in managing weeds, they speed up decomposition of the mulch creating later weed challenges. In the US Northern Great Plains, the prevalence of hard to manage perennial weeds creates a significant barrier to OGNT adoption without a viable management solution.

Yields across the regions paint a bleak picture for OGNT systems. The most successful crop has been soy, matching average regional production levels in Canada, the mid-Atlantic and the Midwest. However, yields are still quite inconsistent in Canada and in the Midwest where OGNT yields still fall 24% behind organic tilled systems though reduced costs of production can make the system more profitable (Bernstein et al., 2011). This may be a function of lower soil temperatures, slower root growth, nutrient tie-up and allelopathic effects of rye (Silva and Delate, 2017).

Corn yields have not met these thresholds in the mature US OGNT systems largely due to lower yielding shorter season cultivars required by delayed planting timing and greater N requirements that cannot be met by legume cover crops alone or cash crop biological nitrogen fixation. In the Northern Great Plains, OGNT systems that were supported by animal cover crop termination led to yield reductions of 50-75% of winter wheat. In the West, OGNT pumpkins in Washington reduced yields by only 20%, but experiments with eggplant, tomatoes and cotton in California led to yield reductions of 80-100%.

Nutrient dynamics, specifically nitrogen management, tended to drive yield responses. Where tillage supports nutrient mineralization in OG systems, in NT systems the cooler temperatures and potential immobilization of nitrogen via surface residue presents significant challenges. In the Midwest one study showed that even while soil nutrient concentrations for N, P, and K were similar across tillage systems, crops in the NT system had less uptake (Bernstein, Posner, Stoltenberg, & Hedtcke, 2011). Some in the region suggest that it is temperatures that drive this process more than immobilization(Andraski and Bundy, 2008). This is a particular problem in organic systems where organic fertility is microbially mediated, as compared to the direct application of ammonium and nitrate in conventional systems (Gaskell et al., 2000). While soy can often overcome this hurdle via biological N fixation, corn has significant N asynchrony problems (Bernstein et al., 2011). Single species vetch cover crops did not provide adequate N in the Midwest or the mid-Atlantic, and also failed to provide adequate weed management (Delate et al., 2012; Wallace et al., 2017). In the mid-Atlantic it is unclear if fall applications of dairy slurry can provide adequate N in the preceding cropping cycle. In the Northern Great Plains OG tillage-based systems are often N-limited, leaving many questions about the potential of OGNT systems.

Despite decades worth of experimentation, these OGNT systems are still in early stages, with most research focused on agronomic aspects rather than more detailed soil chemical and physical changes. Increased surface soil organic matter and microbial biomass and respiration were observed in Germany, with general confirmation of aggregate stability and infiltration observed in more mature regions. However, the literature lacks long-term studies to make significant claims about soil carbon and soil organic matter gains.

Across regions, there was a call for future research to address the lack of available information and affordable equipment. In Canada, the mid-Atlantic and the Midwest, there was also a call for breeding or finding cover crop varieties that matured earlier, whether grasses or legumes, but that would also maintain adequate levels of biomass production. In the Midwest Silva and Delate (Silva and Delate, 2017) emphasized the need for legumes that would terminate earlier to support the corn cycle of standard rotations. The Canadian authors emphasized the need to find and breed cover crop mixtures with synchronous termination timing (Halde et al., 2017). The mid-Atlantic called specifically for better equipment to apply animal products efficiently. The mid-Atlantic emphasized the need to find and breed cover crop mixtures with synchronous termination timing.

Significant progress has been made in OGNT commodity systems, but many challenges still remain. Most adoption has been in the warmer humid regions of the US Midwest, Southeast and Northeast, with little to no adoption in the water limited regions of the northern great plains or the West. Success has been primarily limited to rye/soy crop in a rotational NT system with fall tillage. There has been less success with corn and grain crops which require more nitrogen and have been heavily impacted by delayed planting timings necessary as a result of biologically determined termination timing for cover crops. Balancing nitrogen release from cover crops with higher C:N ratios for residue persistence has been a challenge, with mixed results on the impact of supplemental fertility. High density rye plantings have been largely successful with early season weed management, but more research is needed to address the lack of late season weed suppression and persistence of perennial weeds. Given the importance of cover crop-based mulches in these systems seasonal and field variability of biomass production present considerable hurdles for adoption. There are future research needs for improved cover crop selection and breeding for higher biomass and earlier termination timing, improved equipment design for crop establishment, high residue weed cultivation and supplemental fertility application.

Organic NT Vegetables

The significant research done on OGNT commodity crops over the last 25 years is countered with a much slower pace of experimentation with OGNT vegetable systems. Initial studies on OGNT vegetables coincided with early OGNT commodity crops (Hoyt, 1994; Morse and Creamer, 2006; Morse, 1999). Early experiments with broccoli in Virginia showed equal yield response for no-herbicide in season production when compared with herbicide NT plots (Morse, 2001), while other examples showed the extreme variability of yields in tomato production in California with yields matching tillage treatments in year two of the study, but having dramatic, 90% reductions, in year one (Madden et al., 2004). In the Midwest early trials repeated the dramatic yield reductions for OGNT vegetable systems, showing sustained yield decreases across two years with average marketable yield reduction of tomato (year 1 89%; year 2 65%), zucchini (year 1 77%; year 2 41%), bell pepper (year 1 92%; year 2 79%) (Leavitt et al., 2011). This was supported by trials in the Southeast, showing significant declines in bell pepper yields (71%) with OGNT production (Díaz-Pérez et al., 2006). However, studies in Iowa continued to show some success during a single year tomato study that showed no yield difference between NT and tillage treatments in Iowa (Delate et al., 2012). These mixed early results likely impeded significant early research and adoption.

While early research has been slow relative to OGNT commodity systems there has been a significant uptick in published research in the last 10 years, accounting for 82% of the papers included in this review (n=67), with 40% of those papers published in the last 5 years. Given the diverse nature of vegetables, each with their own unique cropping systems, nutrient requirements, and physiology, I organize these studies by plant families to review overlapping success and challenges across regions. The studies are presented with particular focus on similar areas highlighted in OGNT commodity systems: cover crop management, cash crop systems, yield outcomes, weed suppression, nutrient management, and soil health benefits.

Research on cucurbits has showed consistent, if sometimes inadequate, weed suppression across a broad range of cover crops and mostly dramatic yield declines relative to tillage-based OG systems (Buchanan et al., 2016; Ciaccia et al., 2016; Ciaccia et al., 2015; Skidmore et al., 2019) though some examples of adequate (Montemurro et al., 2013) or excess (Ginakes and Grossman, 2021) production in summer squash. Nutrient deficiencies tended to drive the yield declines, though there was some evidence that specific supplemental fertility could support greater mineralization and crop yield in muskmelons (Diacono et al., 2018). In the northeast different cover crops of barley (Hordeum vulgare L.), crimson clover (Trifolium incarnatum L.), and a mixture had no effect on crookneck squash yield (Buchanan et al., 2016), but, average yields in this study, .33 Mg/ha, represented 3% of regional standards, 10.6 Mg/ha (Atallah and Gómez, 2013). Some research experimented with the use of row covers to enhance production environments with strip till cucumbers, but found that it did not counter balance full width tillage (Lilley and Sánchez, 2016; Skidmore et al., 2019). However, when researchers used plasticulture on top of strip till plots there was no difference between full till plasticulture (Tillman et al., 2015).

In brassicas, broccoli yields showed resiliency, generally performing well in NT systems (Jokela and Nair, 2016b). Broccoli showed favorable performance, relative to a tilled control when used in combination with a vetch rye cover crop and 168 kg N/ha applied as supplemental fertility; though the timing of fertility application (preplant or split) and the type of fertility (chicken manure based pellets as pre plant only or fish emulsion as split application) did not impact yields (Jokela and Nair, 2016b). The authors suggested that the previous cropping cycles may have had a significant impact on yields with the first year yields of 5.4 Mg/ha following a non-leguminous cover crop and 3 month fallow and second year yields of 20.0 Mg/ha achieved in a different field preceded by an alfalfa crop (Jokela and Nair, 2016b). Cabbage yields struggled in NT systems reducing yields by 68-100% across numerous study sites in Europe (Hefner et al., 2020a). However, one study was able to maintain comparable yields with the use of early terminating field pea and a tripling of recommended fertility applications with 100 kg N/ha applied as preplant and 80 kg N/ha applied as a split application a 4 WAP (Hefner et al., 2020b). Cabbage performed well under NT plasticulture with yields matching or exceeding tilled, no-tarp, systems increasing average head weight by 58% (Lounsbury et al., 2022; Lounsbury et al., 2020). However, while average head weights were higher, it was unclear from the site description how this related to plant density (Lounsbury et al., 2020) thus comparable to more standard rates of production. The authors cite that head weight matched seed packet estimates (Lounsbury et al., 2022), but neglected to report on plant spacings in the study. Using best estimates, it appears that while these NT treatments did increase average head weight relative to non-tarped treatments, the maximum head weights still represented ~ 22Mg/ha or ~ 50% reduction in yield from standard production estimates of 44Mg/ha (Daugovish et al., 2008). Though sufficient biomass was reached with rye and rye vetch mixtures, it did not suppress in-row weeds for strip till systems (Maher et al., 2021), but did in rolled NT systems (Hefner et al., 2020b; Jokela and Nair, 2016b), with plasticulture supporting weed reductions up to 50% relative to non-tarped treatments (Lounsbury et al., 2022). Rolled rye vetch mixtures decreased weed growth by 50-68% compared to single species legumes, but decreased yields in cabbage due to decreased available N (Hefner et al., 2020b), accentuating the challenging trade off of nutrient release and weed suppression driven by cover crop C:N ratio. Clear tarps showed the potential to stimulate certain problematic weed species such as crab grass, but black plastic effectively terminated a single species vetch cover crop where a roller crimper failed (Lounsbury et al., 2020). Rye needed vetch to achieve adequate N and rye vetch mixtures outperformed rye only cover crops with supplemental fertility (Maher et al., 2021), but in the northeast cover crops of barley (Hordeum vulgare L.), crimson clover (Trifolium incarnatum L.), and a mixture had no effect on strip tilled broccoli yield (Buchanan et al., 2016). However, average yields in this study, 0.11 Mg/ha, represented only a fraction of the 30Mg/ha summer squash yields expected in California (Molinar et al., 2005).

For leaf crops, lettuce performed well in southern Italy under a rotational NT system with only fall tillage, a vetch cover crop and 140kg N/ha of supplemental applied fertilizer with no difference associated with the type of fertilizer used (anaerobic digestate, municipal solid waste compost, or commercial organic fertilizer) (Testani et al., 2020). Vetch in this system suppressed weeds by over 85% compared to tilled plots (Testani et al., 2020). In a four site year trial in Maryland, a winter killed forage radish cover crop produced NT spinach yields nearly double that of roto-tilled plots with almost complete weed suppression from planting through mid-April (Lounsbury and Weil, 2015)

Solanums have a varied track record of success with many successful tomato yields, though bell peppers have showed mixed (Wang et al., 2015) and negative yield effects (Jokela and Nair, 2016a) and eggplant have also showed considerable yield declines (Hashimi et al., 2019; Luna et al., 2012). Delate et al. showed that NT tomatoes in a single year experiment with two different cover crop mixtures (hairy vetch/rye (Vicia villosa Roth/Secale cereale L.) and winter wheat/Austrian winter pea (Triticum vulgare L./Pisum sativum L. ssp. arvense (L.) Poir.) matched tilled yields with an average of 40 Mg/ha and 67 Mg/ha, while also matching economic returns to production. Both cover crops provided adequate weed suppression for tomatoes, but required 3 and 2 passes, respectively, to reach 90% termination of the cover crop species. The wheat/pea mixture showed slightly decreased yields relative to the rye/vetch, though the difference was not statistically significant both years (Delate et al., 2012). However, where tomatoes were grown with a clover cover crop (Trifolium squarrosum L.) in Italy yields decreased 65% due to weed competition and consistently depressed available nitrate at 0-30cm depths (Abou Chehade et al., 2019). While cover crop biomass was not reported, it is unrealistic that clover would produce biomass thresholds for weed suppression (Teasdale and Mohler, 2000), emphasizing the need for mulch based NT systems. NT eggplant without a preceding cover crop but with the addition of a clipped weed mulch was able to show significant increased surface nutrient dynamics of total and active C, and match yields in Japan (Hashimi et al., 2019). NT bell pepper production decreased by 67% in a NT trial with a mixed cereal rye ‘Wheeler’ (Albert Lea Seed, Albert Lea, MN) seeded at 112 kg ha1 and hairy vetch (VNS; Albert Lea Seed in 2013–14 and ‘Purple Bounty’; Lancaster Agriculture Products, Ronks, PA in 2014–15) seeded at 28 kg/ha cover crop in Iowa (Jokela and Nair, 2016a). While yields across treatments were equal in the first year they also averaged 16.8Mg/ha, representing a 52% yield reduction or standard yields (Hartz et al., 2008).

A few multi-crop trials looked at OGNT practices in complex rotations. In a multi-crop study involving two different cover crops, cereal rye (Secale cereale L.) and winter wheat (Triticum aestivum L.), and three cash crops, bell peppers (Capsicum annuum L. var. ‘Revolution’), snap beans (Phaseolus vulgaris L. var. ‘Tavera’), and potatoes (Solanum tuberosum L. var. ‘Red La Soda’) produced on a hand scale, there was potential for NT plots to match control yields, though it varied year to year and crop. Importantly, this trial experienced highly variable cover crop rates across 2 years with rye declining 23% and wheat 27%, demonstrating the challenge of consistent biomass production (Bietila et al., 2017). In a 5 year multi-crop study in southern Italy with supplemental fertility showed yield declines relative to a tilled control of 50-90% for cabbage and spring lettuce, 90% for summer lettuce, and 40-50% of fennel (Antichi et al., 2019).

Even in rotational NT systems with multiple crops, compost additions drove soil carbon stock increases (Farina et al., 2018) which has been demonstrated in tillage based organic systems as well (White et al., 2020). Ceccanti et al. explored the nutrient density of 4 leafy vegetables and 3 fruit crops and found no significant increases in bioactive properties of reduced tillage based systems in a two year rotation (Ceccanti et al., 2020).

While there has been a pulse of OGNT vegetable research in the last 10 years, many of the results of these need to be examined thoroughly given the rate of catastrophic crop losses. These studies shed light on the basic agronomic challenges of NT production, weed control, equipment, cover crop termination, and crop selection, but more detailed results on SOM accumulation, soil C fractions and microbial biomass should be taken skeptically given the lack of translatability of the specific system. The most successful crops overall in matching yields were tomatoes and broccoli, both of which have expansive roots systems with the ability to grow roots more than 1m vertically in a single season. Other crops fared more variably, but given the matrix of cover crops, soil types and fertility treatments, more research is needed to determine the suitability of specific crops. Summer squash is a prime example, with some trials matching and exceeding regional yields while others suffered catastrophic losses. There is clear success regarding early season weed suppression across crops and regions, though cover crop termination and longer maturing crops still suffered from competition. Some shorter season crops (lettuce, spinach) proved successful in some cases, but more exploration is needed for these crops. Plasticulture proved to be an effective weed management strategy when paired with both NT and strip tilled systems and effectively terminated a vetch cover crop earlier than roller crimper. Most importantly, plasticulture seemed to support yields via increased nutrient availability. High rates (>140 kg N/ha) of supplemental fertility helped to match tillage yields in broccoli, cabbage, tomatoes, and lettuce, but these rates were higher than tillage based organic systems where cover crop biomass and SOM mineralization can account of a significant portion of a N budget (Gaskell et al., 2007). Cover crop and yield variability were also an issue and similar tools recommended in the OGNT commodity literature, high residue weed cultivators and fertility applicators, or strip tillage systems would support grower flexibility.

OGNT vegetables in California

In California there is a dearth of research on organic NT vegetable production, with only one study investigating tomato production (Luna et al., 2012). In large part this is due to California's unique agroecosystem, characterized by high input, high turnover, and high value crops often in complex and diverse rotations. California produces over 400 farm commodities, and is the national leader for vegetables in both value, \$6.33 billion, and area, 1.18 million acres (CDFA, 2016; USDA-NASS, 2017). As the clear national leader in organic production, California accounts for 21% of the total number of organic farms in the US contributing 43% of domestic organic crop sales. California produces over 90% of the nation's organic lettuce, grapes, strawberries, broccoli, celery, cauliflower, avocados, almonds, plums/prunes, walnuts, dates, lemons, figs, and artichokes(Klonsky, 2010). In a study on farmer perspectives in the San Joaquin Valley of California, one grower commented: "We're so high cost, high value you could not grow corn and soybeans only in California and stay in business, whereas in the Midwest they can do that and stay in business. I mean you just couldn't do that here, you couldn't have that rotation here because of our growing costs" (Bossange et al., 2016). This high value system leads to unique complications for NT systems, specifically: 1) the need for early planting, because of either the economic necessity for two to three crops or the importance of retaining moisture in our Mediterranean climate, now more increasingly punctuated by drought, and 2) the sensitivity of fresh vegetable crops, both at establishment/planting (i.e., small seeds and transplants) and as it relates to weed competition and nutrient release.

As a result, California adds new layers of complexity around multiple crops in a season and water limited environments to the existing OGNT vegetable challenges of cover crop selection and management, weed management, and nutrient cycling. Research exploring the viability of multiple crops in single season is lacking, but rotational and strip till practices may be key to these systems. Water lost to late terminating cover crops will likely have to be replaced (Lehnhoff et al., 2017), and studies to assess long term water budgets over multiple years would warrant further investigation.

Future Research

With climate chaos currently ravaging the state (droughts, fires, floods, etc.) a blended OGNT system is needed now more than ever. However, deploying this system in California presents a number of unique challenges that amplify the current struggles of both OGNT commodity and vegetable crops in other regions. While there has been little progress in the State, current research does point towards a research program that addresses specific challenges while acknowledging the significant short comings of current methods.

In order to move the research forward, some bifurcation of research pathways is necessary to more effectively and efficiently make progress. Three potential pathways would be: 1) a focus on basic agronomic challenges (i.e. planting, seeding, high residue cultivation, fertility application and selection), 2) suitability of cover crops and specific cash crop/cover crop combinations, and 3) long-term studies assessing the potential of OGNT systems to improve soil physical and chemical properties. Importantly, there may be different trial designs that suit each pathway.

There is clearly a need to understand and explore some fundamental agronomic questions surrounding OGNT vegetable production. Simple questions around the design of NT equipment (transplanters, seeders, fertilizer applicators) are necessary to ensure that trialed systems maintain a baseline of functionality. There is a huge diversity of planting techniques outlined in current OGNT vegetable studies from hand transplanting to hand held mechanical transplanters to tractor mounted units, reflecting the immaturity of these basic systems. Furthermore, research and development of high residue field and in-row cultivators, and fertility applicators are essential to support both long term and transitional maintenance of these systems. Additionally, the success of rotational NT systems in the Midwest and mid-Atlantic regions should support trialing of these half-way measures during basic system development. Importantly, these functional studies need not conform to the rigors of complete randomized block design. Simple, anecdotal trials would be more cost effective and adaptable, reflecting the important role of informal famer knowledge in the research process (Šūmane et al., 2018). Once adequate progress has been made on the development of these fundamental tools, more thorough field experiments can commence.

One exception to this process is the investigation into fertility applications. Higher than average rates of supplemental fertility may be necessary in these systems as they build towards maturity. Rates exceeding 150 kg N/ha should be a starting point for these studies, given decreased rates of SOM mineralization and cover crop biomass contribution relative to tillage based organic methods. With potentially increased pools for nutrient cycling there is every possibility that this extra fertility will be absorbed by either the crop or the soil-mulch ecosystem, but studies should also assess leaching potential. Further, given the relationship between compost and SOC, heavy compost application rates should be explored. These heavy rates in combination with plasticulture or silage tarping may be a meaningful practice to use in rotation that would both control weeds and boost nutrient availability.

Cover crops play a foundational role in OGNT systems and California systems would benefit from the exploration of different corps and cultivars with specific traits. Cover crops will need to be tailored to the preceding cash crop, similar to existing rye-soy and rye/vetch-corn rotations, but given the diversity of vegetable crop production in California these cover crop-cash crop pairings will likely be increasingly complex. As such, basic research indexing specific cover crops for biomass production, termination timing, and C:N ratio at termination would create a robust menu for growers and researchers to experiment with. Here, certain lower residue, but early terminating cover crops like white mustard, might be suitable ahead of short season lettuce, while rye cover crops may pair better with tomatoes or winter squash. Methods of termination, specifically plasticulture would be important to investigate given potential for early termination, water retention, and nutrient release. A long-term goal for this process is the necessity of plant breeding and selection for new varieties with NT specific traits. This would be true for both cover crops but also for cash crops that may be more successful in nutrient and water limited environments, e.g. the central coast dry-farm tomato (Leap et al., 2017).

Lastly, there should be some parallel long-term studies that address some of the theoretical basis for OGNT and whether it may be able to deliver some of the emergent properties that have eluded conventional NT systems. Namely, that the combination of diverse crop rotations and nutritionally complex fertility sources may support higher levels of SOM and subsequent carbon sequestration than have been achievable in long term conventional NT fields (more detail on this background is provided at the end of chapter 2). Here, trials exploring a continuous OGNT system that combines winter and summer cover crops with high rates of compost or other animal-based fertility would shed significant light on the potential soil chemical and physical processes and water dynamics that could be possible with more progress on the first two research priorities. Conventional NT studies have demonstrated the decades long process of building soil properties and economic returns to investment (Baker and Saxton, 2007) and OGNT vegetable systems are too immature to support a long-term trials including cash crops. Furthermore, repeated 1-3 year cycles of OGNT research keep trial results stuck in a transitional window that may never be able to produce desired outcomes.

OGNT vegetable systems in California are far from being commercially viable and adopted, however, they represent an agroecological model that may be key to managing productive lands in an era dominated by climate change. Despite a huge amount of funding delivered via the California Department of Food and Agriculture Healthy Soils Program, over $70M in 2021, virtually none of this went to OGNT vegetable production. Over 950 projects were awarded in that grant cycle with only 48 including NT practices. Of those, only 4 worked to demonstrate NT on vegetable production with only one of those projects being clearly organic (CDFA, 2023). However, there is incredible value in understanding the potential ecological benefits of these mechanisms outside of a paradigm of economic production. And while ecological innovations like organic and integrated pest management have historically been ignored by the public land grant system and cooperative extension, this may actually be the exact type of research now required by our public agricultural research enterprise.

CHAPTER 2

A LOW-RESIDUE ORGANIC NO-TILL VEGETABLE SYSTEM FOR THE CALIFORNIA CENTRAL COAST

Introduction

No till agriculture systems have grown in importance and application as they have matured, showing important co-benefits related to soil health and environmental protection. The elimination of tillage paired with continuous soil cover in these systems drives a host of secondary benefits, including better aggregation, increased aeration, increased soil nitrogen, preservation of soil structure, preservation of earthworms and soil fauna, improved infiltration, soil moisture conservation and water holding capacity, moderating soil temperatures, natural mixing of soil potassium and phosphorus, improved drainage, and decreased soil erosion and nutrient pollution (Baker et al., 2007a; Carter, 2002; Chaney and Swift, 1984; Hudson, 1994; Soane, 1990).

While the majority of these system operate under conventional management, there has also been significant research on organic no till systems. Most of the published experiments have been conducted in North America and Europe with a focus on commodity crops (i.e. corn, soy, grains) (Carr, 2017). Within those regions there has been extensive experimentation(Vincent-Caboud et al., 2019) in Europe (Navarro‐Miró et al., 2022; Vincent-Caboud et al., 2017), the US mid-Atlantic US (Wallace et al., 2017), the US midwest (Silva and Delate, 2017), and the US Southeast (Reberg-Horton et al., 2012). These studies have identified specific challenges associated with organic NT production revolving around cover crop management, cash crop systems, yield outcomes, weed suppression, nutrient management, and soil health benefits.

Cover crop management in OGNT systems is reliant on grass and grass legume mixtures to achieve adequate biomass for weed suppression approximating 7Mg/ha (Teasdale and Mohler, 2000), with the right C/N ratio balancing in season longevity and nutrient release. In most regions, termination with the roller crimper is adequate for termination. However, there are notable exceptions in the arid west and great plains where successful termination can only be achieved late into the planting season resulting in significant water loss due to cover crop evapotranspiration (Lehnhoff et al., 2017; Luna et al., 2012). While there has been some success with viable returns across regions, mostly in soy due to the crops ability to biologically fix nitrogen(Bernstein et al., 2011), in general yield in OGNT systems generally show reduced yields (Robb et al., 2019; Silva and Delate, 2017). While weeds are generally controlled early in the cropping cycle, late season and perennial weeds continue to present significant hurdles to adoption and crop success (Vincent-Caboud et al., 2019). While some nutrient issues can be addressed with the use of vetch cover crops, or through natural biological nitrogen fixation by the cash crop (i.e. soy beans), fertilization continues to be a challenge (Silva and Delate, 2017; Wallace et al., 2017). Soil health generally has shown improvement (Vincent-Caboud et al., 2019), but at the exclusion of economically viable intersection of yields and expenses (Halde et al., 2017; Silva and Delate, 2017; Wallace et al., 2017).

Fewer studies have looked at organic NT vegetable production (Robb et al., 2019). These studies are very much in their infancy, and while there are ample publications reflecting results, many report vastly different yields year to year (Buchanan et al., 2016; Jokela and Nair, 2016b), or report yield comparisons without reference to standard production expectations, inflating the significance of yield measures (Buchanan et al., 2016; Ciaccia et al., 2016; Ciaccia et al., 2015).

In California there is a dearth of research on organic NT vegetable production, with only one study investigating tomato production (Madden et al., 2004). In large part this is due to California's unique agroecosystem, characterized by high input, high turnover, and high value crops often in complex and diverse rotations (Bossange et al., 2016; Mitchell et al., 2007). This high value system leads to unique complications for NT systems, specifically the need for early planting. Both for economic necessity, with multiple crop cycles in single seasons, and for soil water retention, as cover crop maturation in organic systems requires additional time to mature and results in water loss due to increased cover crop evapotranspiration (Luna et al., 2012).

We sought to investigate the potential to integrate a novel low-residue NT cropping system on economically important crops of lettuce and broccoli in Coastal California. Our objectives were to measure yield outcomes, investigate soil nutrient dynamics of carbon and nitrogen, and quantify soil water and temperature fluctuations. We conducted a three-year experiment in the central coast of California.

Material and Methods

We conducted field experiments between 2019-2021 at the Center for Agroecology at the University of California Santa Cruz (long. –122.0565, lat. 36.9831, elevation 137 m). The soil type of the field is an Elkhorn sandy loam (Fine-loamy, mixed thermic Pachic Agrixerolls) and the field had been in continuous organic management for 41 years. The field had been summer fallowed the during the years of 2017 and 2018 with a uniform winter cover crop planted in each of the preceding fall months. In the fall of 2016, the plots were seeded to a mixture of triticale and vetch at a rate of 134 kg/ha (50% proportion by weight), in the fall of 2017 the plots were seeded to triticale (v. trios888) at a rate of 168 kg/ha.

A complete randomized block design with four replicates was used with full tillage (FT), reduced tillage (RT), and no tillage (NT) as the treatments. The entire field was .0659 ha total and 30m by 21.95m. Plots were six beds wide 5.94 m by 10 m long with soil and biomass sampling taken from center 2 beds and the center 3.33 m of the plot. All cover crops were seeded using a grain drill (Tye series V) in 2018, and subsequently with a NT 3PNT606 grain drill (Landpride Inc., Salina KS) for the remaining trial years. Cover crops were terminated with a 1.83 m flail mower (Gearmore Inc, Chino, Ca) in 2019 and for FT and ST plots in subsequent years. For 2020 and 2021, in the NT plots, cover crops were terminated with a 1.83 m roller crimper (I&J Manufacturing LLC, Gordonville, PA). Tillage was performed in FT plots with a single pass of a 1.83 m spading machine (Falc, Faenza, Italy) to a depth of 30 cm and tillage was performed in ST plots with 3 passes of a 1.83 m tandem disc (Gearmore Inc, Chino, Ca) to a depth of 15 cm. Beds in the FT and ST treatments were listed with a two-row Lilliston cultivator (Bigham Brothers, Inc., Lubbock, TX). Plots were fertilized ahead of rototilling/shaping/planting with a fertilizer applicator (Clamco, Gilroy, CA) that was custom modified with straight coulters for the NT plots. Lettuce and broccoli were planted with a two-row mechanical transplanter 5000 series "sled type" (Mechanical Transplant Co., Holland, MI) with between row spacing of .279 m and in row spacing of .30 m for a plant density of 71,759 plants per ha. NT plants were planted using the same planter with additional custom fabricated NT implements (fabricated by Darryl Wong) that included a 5.08 cm "8-wave" coulter (Yetter Co., Colchester, IL) followed by a 1.58 cm curved cultivation shank or "pick" ahead of the planting sled. Both plantings were irrigated overhead at planting, 1 DAP, 4DAP, and 8 DAP, before transitioning to high flow drip tape for the remainder of the crop cycle. Drip irrigation water was applied 3 days a week through the growing season ranging from .5cm to 1.5cm per week based on regional Et0 and growth stage. All plots and crops were tine weeded (Treffler, Pöttmes-Echsheim, Germany) with two passes during overhead irrigation and furrow cultivated using a custom three-bar cultivator (fabricated by James Leap). Lettuce and broccoli in the FT treatment was tilled with 2 passes of the 1.83 tandem disc, while the ST treatments were terminated with the use of a 1.83 m undercutter bar (fabricated by James Leap) that worked 10 cm below the surface, terminating crops and weeds without inverting the soil.

In 2018 mustard cover crop (Sinapis alba ‘White gold’) was sown initially on November 20th ahead of our first significant winter rains. However, due to low stand establishment and heavier than expected co-emergence of weeds, the entire plot was tilled one final time January 5th 2019 and re-sown with mustard (Sinapis alba ‘White gold’) at 16.8kg/ha. This mustard was grown out until late April, and was mowed at full flower. As anticipated, the NT plots saw complete termination of the mustard cover crop. The full tillage (FT) plot was spaded to a depth of 12” and listed up, while the shallow till plot was disced with 3 passes to a depth of 4” and then similarly listed up. Planting was originally scheduled for May 6th, however, in May California experienced an unprecedented storm system that saw portions of the state receive around 400% of the monthly average. Planting was postponed until after the system passed and in early June that the tilled plots were workable again. The NT plots were ready earlier, due to the increased evaporative capacity of the more densely aggregated soil, but planting was delayed to accommodate the entire plot.

Data Collection

For yield analysis, plants were harvested from the center two beds of each plot at the center 3.33 m of each plot. Lettuce and broccoli were separated into marketable and unmarketable yields based on observation, with the same person assigned to make consistent separations for each harvest in all three of the years. Heads were weighed and counted at the field.

Soil samples for nitrogen were taken approximately monthly throughout the duration of the trial. Samples for 0-15 and 15-30 cm were taken from center two bed of each plot and the center 3.33 m using a soil probe (2 cm). For each plot 10 subsamples were taken to make a composite sample in a 5g bucket, transferred to a labeled Ziplock bag and placed in a cooler on ice, and transferred to the laboratory where samples were kept at 4 degrees C until extraction. At the laboratory, ~5 g of soil was taken from the composite sample and transferred into a pre-weighed screw top plastic tube containing a 25 mL of 2 M KCl and extraction was done within 48 h of the sampling. NH_4-N and NO_3-N concentration in the KCl extracts were determined by flow injection analysis methods (Lachat Intruments, 1993a, 1993b). To determine gravimetric soil moisture content ~100 g of soil was taken from the composite sample and dried.

Soil samples for carbon were taken on an annual basis in March. Samples were taken from center two beds of each plot and the center 3.33 m using a soil probe (2 cm). Samples were taken at 0-15 cm, 15-30cm, 30-60 cm, and 60-90 cm. For each plot 10 subsamples were taken to make a composite sample in a 5g bucket and were transferred to a labeled Ziplock bag. Samples were shipped to California State University Chico and processed in the Regenerative Agriculture Demonstration Lab.

Results and discussion

NT plots showing continued depressed production across all three years compared to the tillage plots for broccoli and lettuce. For the lettuce crop, in all three years, there was no significant difference between the FT and ST treatments. However, the average harvest of the NT plots compared with the combined FT/ST average varied from year 1 to year 3 at 5%, 33%, and 20%, respectively. Only years 1 and 3 showed a statistical difference between the FT/ST treatments and the NT treatment.

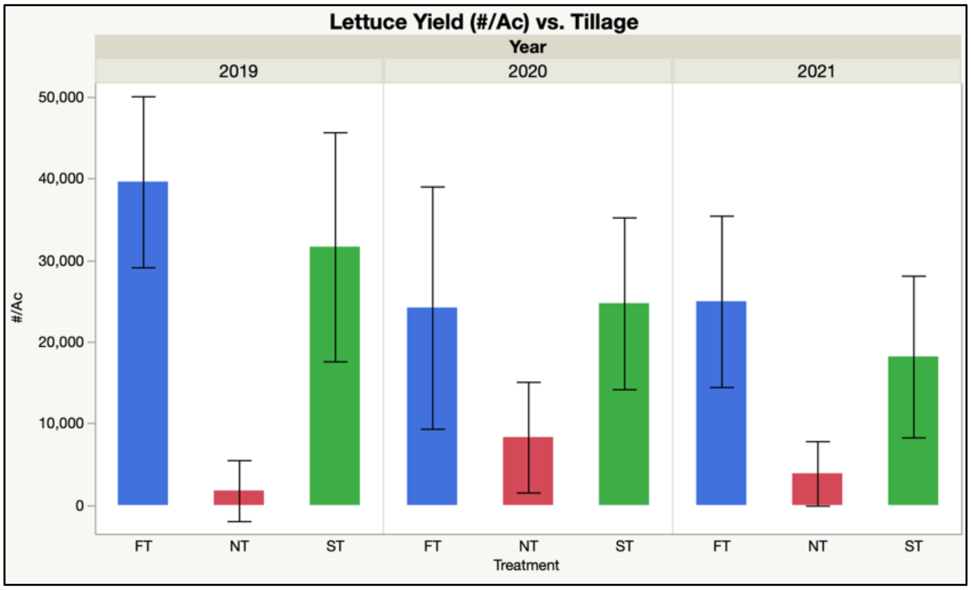

Figure 2.1: Lettuce Yield

For the broccoli crop, there was no significant difference between all three treatments across the three years. However, average NT yields did show a clear trendline indicating consistently lower yields than the FT/ST treatments. While there was no difference in year one, in years 2 and 3, there was a 25% and 33% reduction in yields compared to the FT/ST combined average.

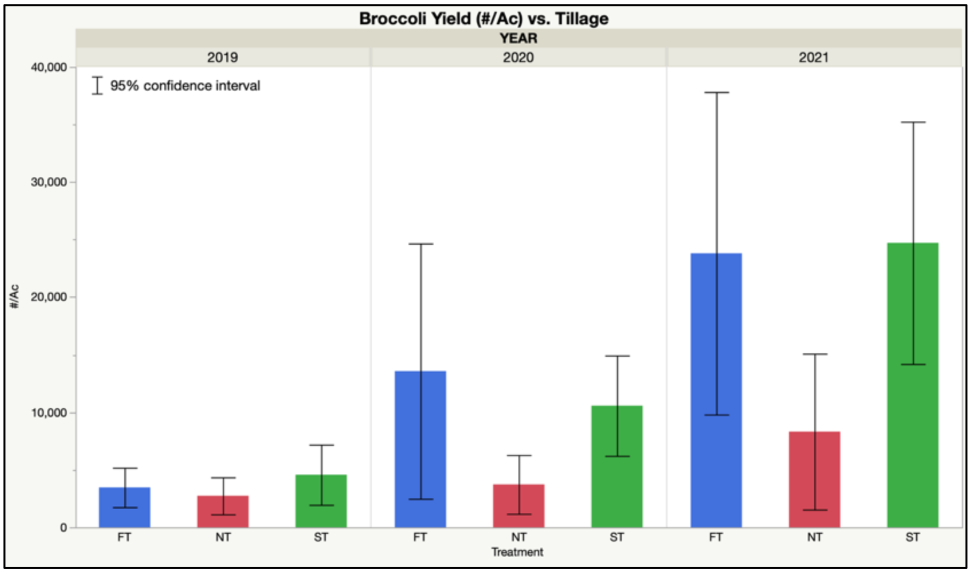

Figure 2.2: Broccoli Yield

The yield data shows a difference between the lettuce and the broccoli yields, with NT lettuce seemingly struggling more than broccoli to produce a similar yield to the tillage treatments. This could potentially point to crop suitability for NT production. Broccoli, while it has a higher nutrient demand than lettuce, also has a much deeper and more active root system which could have accounted for some of the difference.

Additionally, it appears that the NT yield data is more tightly clustered than the yield data in the FT/ST tillage treatments. This may have simply reflected yield variability, but these figures were also impacted by plant loss via gophers or disease. In years 2 and 3, there was a significant outbreak of clubroot, which depressed yield figures in two of the reps. Clubroot is rarely present at the study site and only shows up in low-lying winter production beds that do not receive adequate drainage during the rainy months. Likely, the irrigation schedule and layout required by the replicated plot design were responsible for the incidence of some of this disease. Additionally, gopher presence did impact specific plots in the tillage treatments. This plant loss may have skewed the yield data creating more variability in the tillage plots, specifically in the broccoli years, which would impact the lack of significant difference between the FT/ST treatments and the NT treatment and overestimate the potential of NT broccoli to match yields.

Lastly, the trial began to show some yield trendlines within the NT plots. While the lettuce showed decreasing yields over the three years, the broccoli conversely saw a generally increasing trend. There are no long-term studies on these specific crops in organic NT systems to compare this data with to understand whether to expect these trendlines. There is a possibility that broccoli yields would continue to increase with commensurate improvements in soil quality. Conversely, lettuce yields could have the potential to experience continued and potentially compounded challenges.

Soil Nitrogen

The Inorganic N data continued to complicate the picture between tillage systems. In 2019 lettuce, a field standard of 56kg/ha of nitrogen was applied, however, after the yield drags in that first crop, rates were doubled to 112 kg/ha for the subsequent broccoli crop. There is a clear peak in total N in September 2019. However, while there was sufficient available nitrogen, even in the NT plots, all tillage treatments saw significantly depressed yields compared to a 15 Mg/ha average yield in our region and subsequent yields in the field.

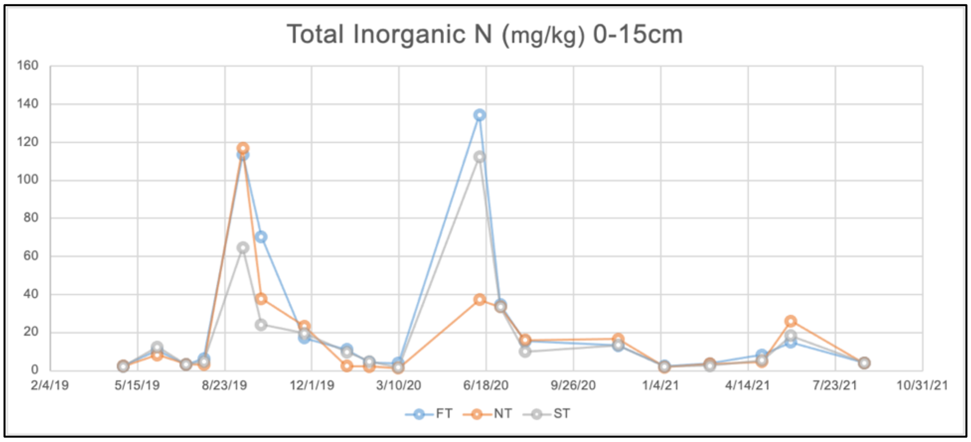

Figure 2.3: Total Inorganic N 0-15cm

Moving into 2020, we again provided double fertility for the spring 2020 lettuce crop. While there was a clear spike in total N in June 2020, there is also much less available in the NT plots relative to the tillage plots. One potentially confounding factor is that irrigation switched from a single line of drip in year 1 to 2 lines of drip in years 2 and 3. This was a change in response to the potential challenge of the NT plots to retain moisture and the potential for more broad moisture application. However, this change also resulted in drip lines no longer centered over

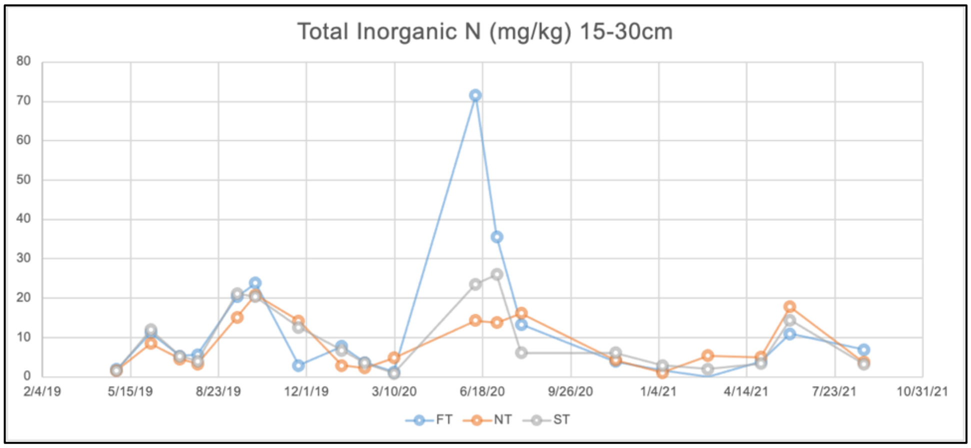

Figure 2.4: Total Inorganic N 15-30cm

the fertilization band. Lack of adequate moisture for the pelleted fertilizer could have resulted in less mineralization in the NT plots compared with the tillage plots, where the fertilizer was more evenly distributed.

In 2021 there was no longer pelleted guano available on the market, and a poultry litter and feather meal product was applied instead. While the nitrogen contribution was still the same on kg/ha basis, these fertilizers can mineralize at much slower rates (Gaskell et al., 2007). While we continued with the higher 112 kg/ha fertilization rates in June 2021, we did not see a similar spike in total N in 2019 and 2020. During this period, there was no significant difference between the total N levels between tillage treatments, with the NT having the largest average N available.

Gophers

During the trial, there was no significant difference between gopher loss by tillage treatments. For the lettuce, there appeared to be a potentially worsening trendline for both the crop and the NT treatment relative to the other tillage treatments. There was no significant difference between the survival rates except between the NT and FT treatments in 2021. That said, the mean survival rate

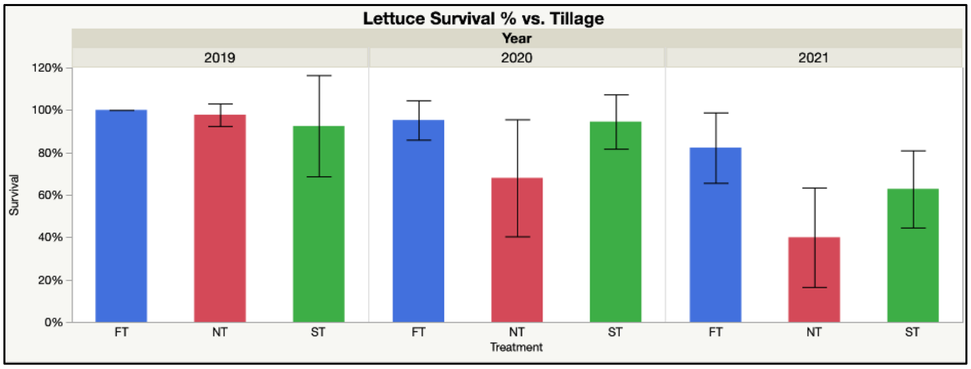

Figure 2.5: Lettuce Survival

appeared to decrease faster for the NT treatments than the tillage treatments. For broccoli, the data across treatments shared a similar level of variability. While the average survival rate of the NT plants trended less in 2019 and 2021, it was also equal to the ST rate in 2020.

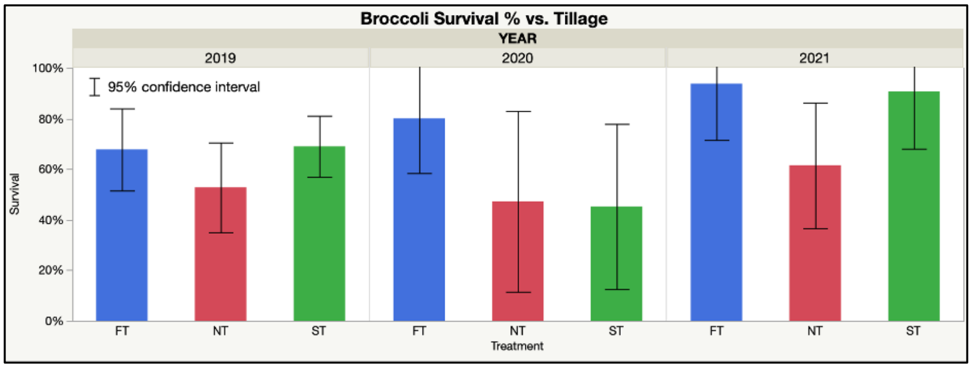

Figure 2.6: Broccoli Survival

Water

While water retention initially appeared to be an issue with our low residue NT system, there were mixed results with two full years of data. Once we switched

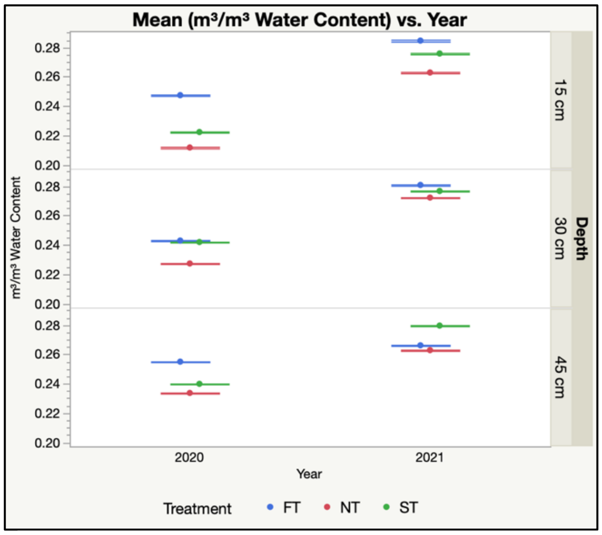

Figure 2.7: Mean VWC

from 1 line to 2 lines of drip tape in the lettuce in 2020, we did not see the same excessive dry-down pattern that we had seen in the tensiometer readings on the 2019 broccoli. Lettuce produced a very similar dry-down pattern to the tillage treatments, at times reading drier and wetter. A similar pattern was observed in the broccoli treatments, with very similar dry-down patterns between the tillage treatments. However, there was more dry-down in the NT treatments at 0-15 cm. Across all the composite data for the two years and crops, there was less moisture in the NT plots. In some of the graphs, NT plots began with less moisture and never recovered. With similar amounts of water were applied in all years (bar one accidental irrigation), the initial and subsequent dryness is likely a result of extra moisture loss due to lack of tillage and the continued cumulative loss of evaporative moisture over the period.

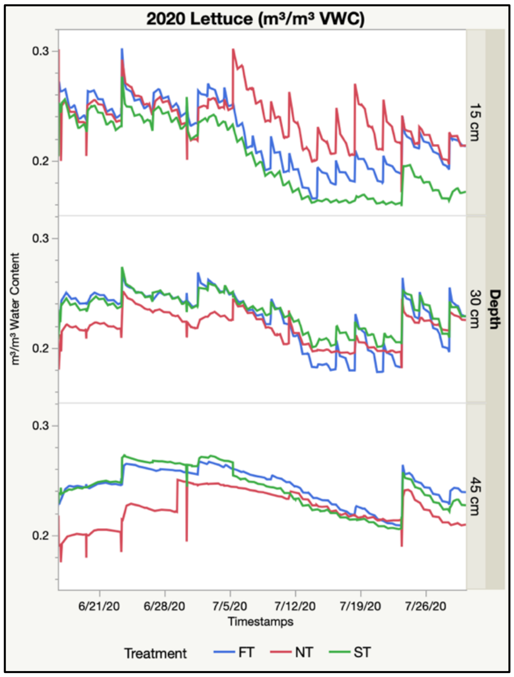

Figure 2.8: 2020 Lettuce VWC

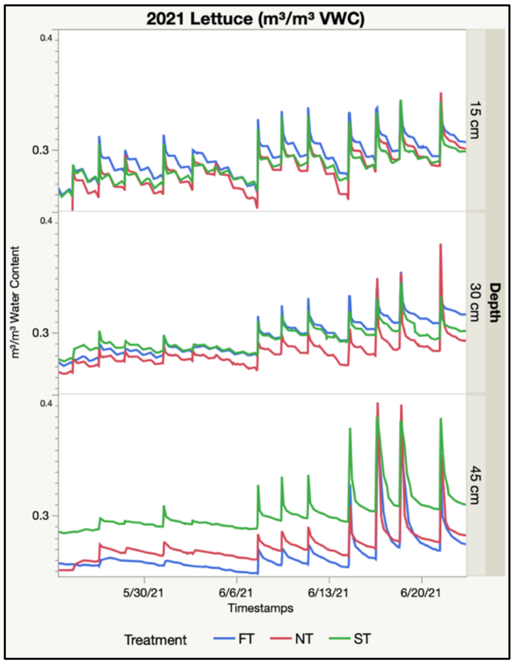

Figure 2.9: 2021 Lettuce VWC

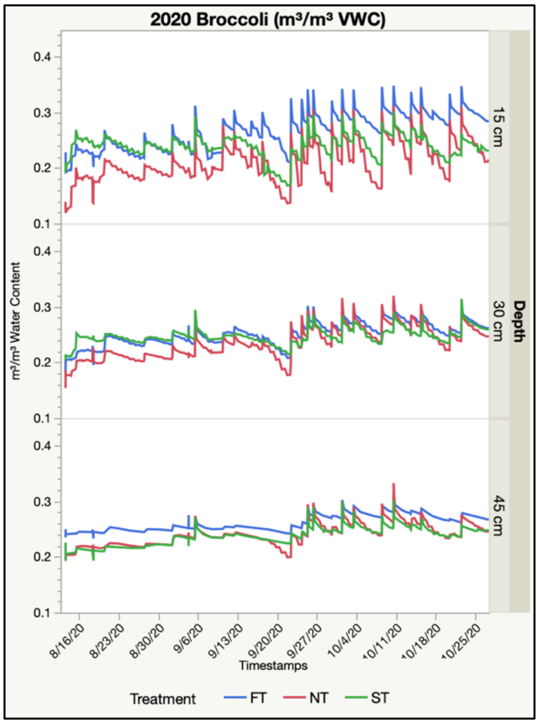

Figure 2.10: 2020 Broccoli VWC

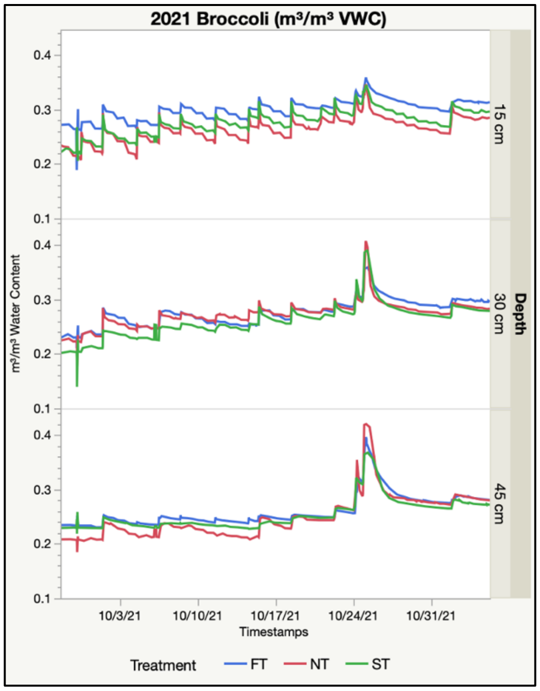

Figure 2.11: 2021 Broccoli VWC

Temperature

The temperature readings from the trial continued to demonstrate the potential cooling effect of tillage relative to a no-residue NT system. Across the two crops and two years, there was clustering of data within ~.5 degrees F at the 30 and 45 cm depths. While there was more spread at the 15 cm depth, the average temperatures (degrees F) were still 66.8 (NT), 66.4 (FT), and 66.2 (ST). So, while significantly different, the absolute difference between these temperatures may still not have been particularly meaningful. When separating the data, it appears that most of this variation could be accounted for in the lettuce crop, where likely the lack of extensive canopy cover allowed for more significant soil warming in the NT plots

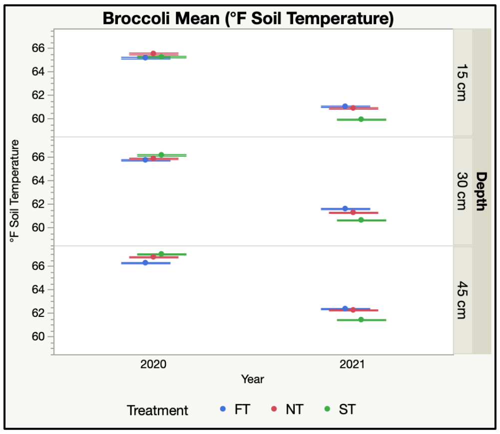

Figure 2.12: Broccoli Mean Soil Temp.

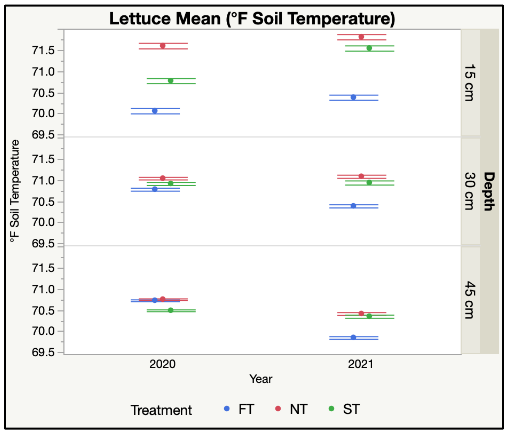

Figure 2.13: Lettuce Mean Soil Temp

Soil Carbon

In reviewing data on percent soil carbon and the labile C fraction (POXC), there was no significant difference across any of the years and any of the depths and no trendlines. While soil percent C is slow to change, there is evidence that the more labile C fraction can respond closer to an annual cycle. However, there was no indication of any difference between tillage treatments. Previous studies have seen increases in this fraction when studies look at the impact of cover crops compared with no cover crops (White et al., 2020). Because all the treatments had multiple cover crop cycles in a year, it is possible those cover crops had a more substantial impact than tillage in this trial. Additionally these results may be more indicative of the potential of diverse FT rotations that still represent reduced or conservation tillage to maintain soil carbon. The FT treatment in this trial represents a form of conservation tillage relative to standard tillage passes in California (Mitchell et al., 2016). Additionally, this soil has been managed in this way with regular cover cropping and compost amendments for over 40 years which allows the soil to operate more functionally with less amendments than might be expected (Muramoto et al., 2011).

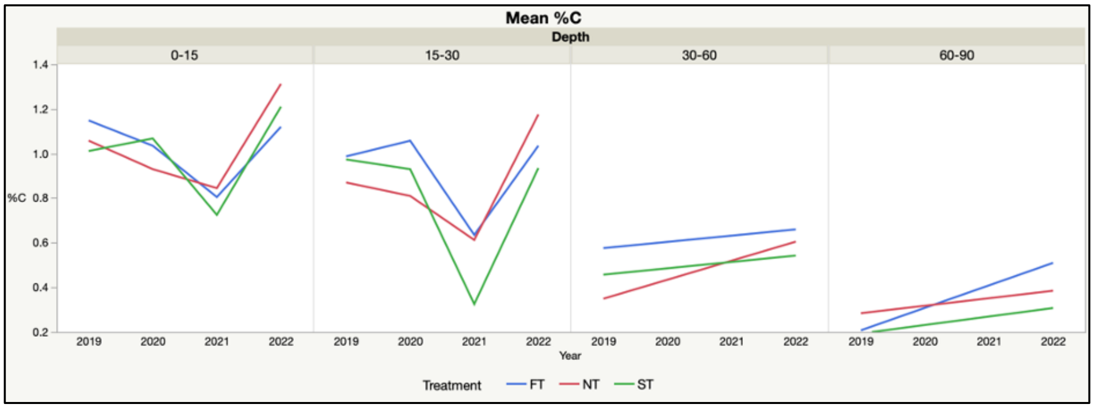

Figure 2.14: Mean %C

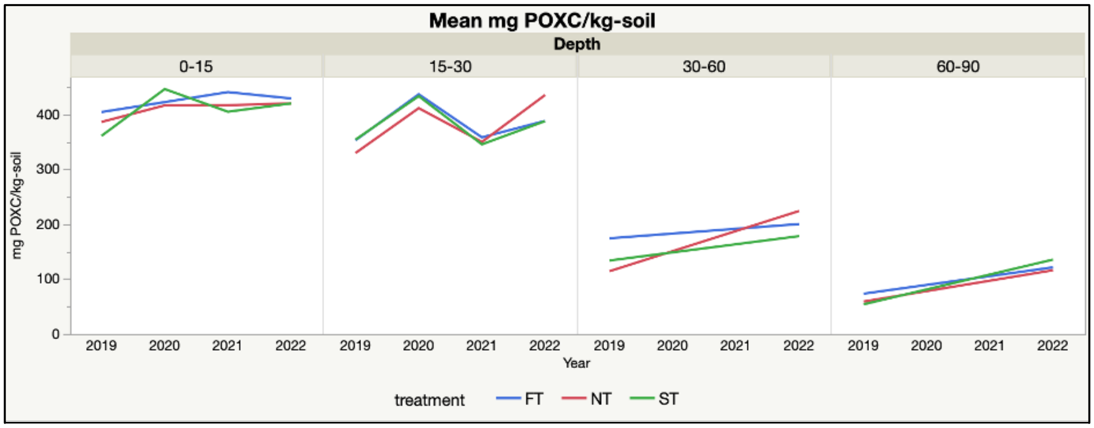

Figure 2.15: Mean mg POXC/kg-soil

Future Directions

This field trial has followed with past precedents in OGNT research, focusing on agronomic systems questions to establish viable methods of production and specific cover crop-cash crop relationships. While results have underscored current challenges around reduced yields and nutrient mineralization and assimilation challenges there is still considerable interest in combining organic and no till systems to achieve the "Holy Grail" of cropping systems (Lehnhoff et al., 2017). While these systems obviously pair important sustainability goals of soil conservation and the exclusion of synthetic pesticides and herbicides, there is also the potential that the interactions of these systems may lead to more emergent systems properties, supporting increased nutrient cycling and SOM accumulation that have eluded conventional NT systems while simultaneously addressing nutrient cycling deficiencies in organic tilled systems. This potential is based around systems like the study site and others in the state that have employed stacked organic practices and reduced or mindful tillage for decades; systems that this author and others colloquially refer to as ORG+. While there are still few examples of successful systems to support OGNT production in California, the integration of these ORG+ systems with NT practices still presents a theoretical foundation for expanded agroecosystem benefits. To further explore the potential it is useful to describe the relationship of carbon and nitrogen cycling in tilled organic systems as it relates to nutrient management.

One of the defining factors of organic systems is the exclusion of synthetic N fertilizer, which is often applied in an inorganic form in conventional systems. Inorganic fertilizer is applied in a form that is readily available to plants for immediate uptake and precise dosing. In contrast, organic fertilizers, amendments, and cover crop residues are applied in an organic form requiring the process of mineralization for nutrient release. This microbially driven process, with specific environmental parameters, makes the eventual output of inorganic N highly variable based on time of year, temperature, moisture, and, importantly, C:N ratio of the amendment or cover crop itself. Research has shown that even when organic amendments have the same relative percentages of N, that the amount mineralized under controlled conditions will vary based on the fertilizer feed stock (Gaskell et al., 2007).

An additional challenge of this variable release is synchronizing the biological release of nutrients with crop needs. Cover crop residue and organic fertilizer, especially in biologically active soils, tend to mineralize quickly in the first couple weeks from planting (Gaskell et al., 2007). While this synchronizes reasonably well with short maturity vegetables (spinach, lettuce mix, etc.), for longer maturity vegetables (broccoli, cauliflower, cabbage, peppers, etc.), crops will only use 25% of their total nitrogen draw in the first 50% of their growth process (30-50 days) (Smith et al., 2013). Additionally, due to the variable nature of mineralization, there is still the high potential for leaching at the end of season, if previously inaccessible nitrogen becomes available and in the absence of fall cover crops (Askegaard et al., 2011).

While asynchronous N release is a challenge in organic systems the complex nature of these amendments and residues also provides additional nutrient cycling benefits. The additional carbon in organic amendments paired with the applied nitrogen allows for a tighter coupling of these nutrients in the soil system influencing greater total N retention when assessed as N in the crop and the soil (Gardner and Drinkwater, 2009). Furthermore, a meta-analysis of 56 independent studies of conventional and organic farming systems showed that multiple indicators of microbial health increased (microbial biomass C, microbial biomass N, total PLFA, dehydrogenase activity, protease activity, urease activity) in organic systems, likely attributed to the diversity of organic inputs in these systems (Lori et al., 2017). Still, others have found that microbial diversity is less effected by farming system than by crop rotations and intensity of production (Lynch, 2015).

The requirements of the National Organic Program and general traits of ORG+ systems can often be quite different. This is particularly the case as it relates to crop diversity in organic systems, in particular cover crops. While cover crops and crop diversity are not technically required in national guidelines, they are widely used in ORG+ systems. This additionally relates to the use of cover crops in conservation tillage systems as well; while some systems employ cover crops and crop rotations, many do not. Thus, it is useful to discuss cover crops and crop diversity as a stand-alone system trait in understanding the specific effects on nitrogen and carbon cycling.

Crop diversity, and cover crops in particular, play an important role in the carbon and nitrogen cycling, and are foundational in ORG+ systems. The inclusion of leguminous cover crops greatly increases the amount of plant available nitrogen via biological nitrogen fixation. Because cover crops are typically incorporated as green manures, with relatively low C:N ratios before fixed N is locked up in seed formation, much of the fixed N becomes available as metabolic carbon residue (Doran and Smith, 1991). Both legume and non-legume cover crops will also impact nitrogen availability as a portion of that residue adds to both the active and the slow SOM pools. While long-term comparative studies have indicated that organic systems may be able to maintain SOM levels relative to conventional systems (Lynch, 2015), trials that compare the effect of cover crops on SOC, as a proxy for SOM, tend to show an increase (Poeplau and Don, 2015). Cover crops also play a role in changing not only the quantity of SOM, but the also the quality. Multiple studies have shown that the inclusion of cover crops, increases the active SOM pool. This is largely explained as increased carbon inputs from cover crop growth facilitate microbial assimilation into the soil microbial biomass (Jans-Hammermeister et al., 2018). This fraction is most readily mineralizable for crops, thus driving yield increases as well (White et al., 2020). There is increasing interest in the specific role that root exudate carbon plays in this process; because it is both more labile and produced below ground, it is more microbially accessible for assimilation and immobilization, which is an important pathway for SOM formation (Cotrufo et al., 2013). This distinction could potentially explain a differential impact between living cover crops and organic amendments. Lastly, this increase in microbial activity has a concurrent effect on aggregation which further protects SOM as well as increases water holding capacity, which will decrease leaching and erosion losses of N.

Our trial design incorporated diverse cropping systems, with both summer and winter cover crops, as well as organic fertilizer sources. However, it failed to incorporate compost additions and cover crop biomass was sacrificed for ease of termination and ease of cash crop establishment. These are both areas for investigation in future trial design and research.

The reduction in tillage of NT systems also has profound impacts on mineralization and resulting SOM accumulation. In NT systems, SOM is increased through the frequent application of organic mulches and simultaneous breakdown of root biomass. Meanwhile, the elimination of tillage passes that stimulate microbial breakdown and oxidation of existing pools of SOM through increased soil temperatures, oxygen and water, can further increase SOM levels. However, while these increases in SOM have marked impacts at the soil surface, trials that compared rates of SOC and SON at deeper depths observed there was no significant difference in nutrient accumulation, only a difference in vertical distribution; NT systems tended to concentrate nutrients at the surface, whereas tillage systems accumulated more nutrients at deeper depths (Baker et al., 2007b; Dimassi et al., 2013). Olson and Al-Kaisi confirmed these findings when looking at SOC accumulation in a 20-year trial comparing NT and moldboard (MP) plow treatments. They found that SOC in the NT treatment was increased over the trial period in the 0-5 cm range, but actually decreased against the baseline in the 5-35 cm range. Additionally, the MP treatment showed higher levels of SOC accumulation in the 20-35 cm layer than the NT treatment (Olson and Al-Kaisi, 2015).

When assessing NT systems for effects on net mineralization, results are mixed. The increase in SOM at the surface combined with the improved water and temperature dynamics of mulch may have the potential for greater N mineralization at the surface. NT systems may also decrease potential N immobilization due to the minimized soil contact of residue C. Conversely, these benefits may be offset by the lack of mineralization in the absence of tillage and the lack of incorporation of residues to deeper depths (Recous et al., 2019). Furthermore, decreases in N mineralization at the surface of NT soils has been observed, mainly as a function of decreased soil temperatures (Andraski and Bundy, 2008). Oorts et. al. (2007) reported no significant differences between two sites comparing NT and deep plowing over 33 and 12 years in net N mineralization rates. Similarly, in studies on the net plant assimilation and immobilization of N fertilizer in NT compared to deep tillage systems, there was little to no difference observed (Giacomini et al., 2010; Karlen et al., 1996).

Thus, when addressing the implications of NTORG+ systems of primary interest is the mineralization-immobilization-assimilation dynamic, as it relates to both adequately supplying crop N and solving the issue of asynchronous release. While research on existing NT systems has shown no net N mineralization, these studies have not indicated the degree to which organic additions and crop diversity/cover crop inclusion, practices common in ORG+, would affect the potential for greater N cycling, both in assimilation and mineralization. Given that both of these practices have been shown to drive labile C additions, better couple C:N ratios for assimilation, and improve microbial activity indicators, it is possible that the combination of these practices when coupled with NT may result in greater and more sustained N release. Indeed, while microbial biomass assimilation involves a period of immobilization, plants tend to benefit over the subsequent period of weeks to months (Renwick et al., 2019). Given existing challenges of nutrient balancing in

OGNT systems, it should be assumed that leguminous cover crops would be a key component of these systems, but they were excluded from this trial due to known challenges with termination in California (Luna et al., 2012). However, given the highly climate dependent performance of cover crops, it is not likely that managers will be able to rely on them solely for crop nitrogen and supplemental fertility sources will likely play a vital role in attempting to achieve current commercially viable rotations. It will be important to understand differences in crop uptake in NT systems across different forms of organic amendments: liquid, pelleted, and compost. Understanding environmental factors, such as soil temperature, that impact N availability will be important to determine season specific application rates.

Given the importance of surface soils in providing N mineralization in NT systems, NTORG+ systems will also need to maximize this potential, likely through the use of high residue cover crop mulches that will favorably impact the moisture and temperature dynamics in that crucial range. This trial investigated a low-residue NT system given the challenges with cover crop termination and crop timing. However, the consistent challenges in producing yields, despite excessive fertilization and even available N, while maintaining higher soil temps coupled with increased water loss reflects a system out of balance and had the inverse relationships expected from the literature (Hoyt, 1994). Given these findings, it would be hard to recommend future exploration of this particular technique and points to the importance of soil cover in connecting the critical benefits of potential NTORG+ systems.

In irrigated systems it will be important to understand the impact of different irrigation systems (drip, furrow, overhead) on surface soil wetting patterns, subsequent microbial function and, N release. While many irrigated systems can be water limited, strategic use of specific irrigation modalities may provide some benefits when coupled with increased water holding and retention capacities.

Cash and cover crop diversity will also be key NTORG+ systems for maximal use of the soil potential for nutrient storage and release. Specifically, how rooting architecture and crop phenology could be utilized to support the additions of labile C deeper in the profile, while also acting as nutrient pumps to retrieve stored nutrients from deeper in the profile (Renwick et al., 2019). This may even involve research on breeding and selection for specific traits that support both nutrient availability but other important traits for NT production (Lyon et al., 2015) that has been echoed consistently in the OGNT literature (Silva and Delate, 2017). Yield data from this trial highlights these differences between cash crops, with broccoli showing a much more promising yield trend than lettuce.

Given the potential benefit of NTORG+ systems, the complexity of interactions, and the current challenges facing cash crop establishment in OGNT vegetables, a productive vein of research would explore the impacts of a NTORG+ rotation that excludes cash crops, saving investigators the existing challenges of cash crop management. A system that includes heavy applications of compost to drive soil carbon stocks (Farina et al., 2018; White et al., 2020), diverse winter and irrigated summer cover crop rotations with the exclusion of tillage could provide interesting insights into the potential of soil nutrient interactions while simultaneously allowing parallel agronomic research to continue for current cash crops challenges.

CHAPTER 3

THE COOPERATIVE EXTENSION SERVICE: A CONTESTED HISTORY AND CONSTRAINTS ON AGROECOLOGICAL INNOVATION

Introduction

Given the robust nature of the United States Cooperative Extension Service, with annual federal appropriations of $550M, (Benson, 2022; Warner and Christenson, 2019) and the promise of organic no till (OGNT) systems, it may seem surprising how peripheral research has been to date. However, previous agricultural innovations such as organic systems (Padel, 2001) and integrated pest management (Warner, 2008) have also encountered a similar problems of exclusion from formal extension and research. These exclusions can be understood via critiques of the CES as failures of 1) agenda, namely the prioritization of market integration over social or environmental outcomes (Buttel and Busch, 1988) and 2) practice, utilizing an outdated diffusion of innovation model increasingly ill-suited for complex socio-environmental challenges (Röling and Wagemakers, 1998). These contemporary critiques of the CES are not novel, the issues of market assimilation at the expense of rural livelihoods and the privileging of academic expertise over farmer knowledge have been at the heart of the CES' contested history. And yet, the CES is also a unique government organization, designed with populist roots, supported with federal appropriations, and with local autonomy that has honed its ability for outreach in over 3,000 counties over decades of service. As future agricultural innovations are required, it would be foolish to ignore the embedded potential of the CES and to ignore the historical debates around agenda and practice, importantly, identifying where meaningful partnerships between the CES and the people were made.

The contested history of the cooperative extension service

When assessing both the challenge and promise of the cooperative extension service today, it is imperative to understand the contested history in which it arose, the competing factions and ideals that lead to its current manifestation and the changing economic and demographic realities that both shaped its evolution and that it too had a hand in shaping. The story of the CES in the United States is one of uniqueness and sameness. There is genuinely no other form of government like the extension service, precisely the cooperative arrangement it shares with federal, state, local, and private parties. This structure established two defining features, local responsiveness and adaptability, features not frequently associated with government programs, let alone those as large as the CES. Despite this uniqueness, the history of the CES showed an altogether expected sameness in its inability to insulate the American people from the externalities of unfettered growth. The march of American agriculture trough the 20th century is one marked by incredible productivity and consolidation, leaving a trail of displaced and underserved farmers in its wake.

While this inability is not altogether surprising, it is made somewhat paradoxical for three reasons. First and foremost, the CES was created explicitly to protect and serve the rural farmers and communities that have been left behind. Second, the efficacy of the CES to reach and affect the American people is rarely questioned, whether by supporters or critics. In its adaptability and responsiveness, the CES has mobilized millions of people and implemented dozens of government programs throughout its history. Third, far from playing a role in slowing or preventing the industrialization of American agriculture, the CES was, instead, instrumental in its development. This tension is present in the CES throughout its history, both at its inception and continued today: whom to serve and how best to serve them?

Perhaps it is unfair to expect any particular organization, let alone one as embedded in the federal government as the CES to be able to hold a separate view to the prevailing emphasis of economic performance; however, with its explicit call for service and its unique structure, these questions persist today with more visibility than in other sectors of government. As such, it speaks to the promise of the CES in adapting and changing to meet the needs placed upon it. As we move into the 21st century, we must actively assess the role of the vast network of extension and its potential for delivering, as it has so often before.

Agricultural education has its beginnings soon after the founding of the United States. In the early years, post-independence, George Washington made a call for an office that would promote agriculture, claiming that these investments by the “public purse” were “very cheap instruments of immense national benefit.” In the post-independence US, 90% of the population lived on farms, and this investment was seemingly easily justified. However, early attempts at agricultural education were minimal, with most happening informally or under government directives in the manner of federal efforts to share seeds, plants, and animal breeds. In 1839, over 40 years after Washington's call for federal support, congress allocated $1000 to the collection of agricultural statistics and included agricultural questions in the census. This collection of stories and on-farm experiments became the first attempt of the government in acquiring and disseminating agricultural information (Graham, 1990).

While the federal government was slow to move, local farmer groups and states moved to create their own agricultural education systems. At the turn of the 19th century, state societies for promoting agriculture began emerging as well-to-do gentlemen farmers began to exchange ideas, and farm journals began publishing farm achievements and successful methods. While education for the general population was nearly universally supported by the founding fathers, almost all of the early institutions ignored agriculture. The agricultural societies and farm journals called for more focus on agriculture, and while some private institutions surfaced, they were short-lived. Some states took up the call and created state agricultural colleges without the support of the federal government. However, critics suggested that more federal support was needed to extend this education nationwide.

While the percentage of the population that lived on farms had decreased to 50% by 1850, it still represented 11.7 million people and 64% of the workforce. Against this backdrop, the push for agriculture education found a voice in representative Justin S. Morrill of Vermont. Morrill presented the first version of what would be the Morrill Land-Grant College Act in 1857, proposing that grants of land to each state would be sold to establish colleges that would relate to "agriculture and the mechanical arts." While the act passed both houses of Congress, it was vetoed by President Buchannan on constitutional grounds. In what would be one of the first battles around agenda setting for agricultural education, critics in the southern states, argued that these colleges, and the potential democratizing effect that they would have on agriculture, would increase the number of non-slaveholding farmers. This could eventually endanger the balance between slave and non-slave states. In was not until the southern states seceded, that the act could be proposed again in 1862. Needing support for the mounting war effort and his impending re-election from the mostly anti-war mid-west, Abraham Lincoln signed the Morrill Act into law. While the first Morrill Act granted land, it was not until 1890 that congress approved direct annual appropriations for the land grant colleges in the second Morrill Act. These annual payments were contingent on prohibiting racial discrimination in admissions. New colleges created under this protection are known as the 1890s colleges and have in their ranks some of the historically black colleges in the country today. However, the second Morrill Act provided language that required that funds be equitably, not equally, distributed. As a result, many states defined the agenda of who these agricultural appropriations would serve, restricting the number of funds that would support the non-white population. While supposedly equal to the 1862 colleges in all other ways, the 1890s colleges would receive only 0.5% of the total USDA funds allocated to land grant colleges over the next 80 years.

Despite the overt racism of the second Morrill Act, it is worth noting here the uniqueness of the endeavor and how distinct it was from previous versions of higher

Table 3.1: Timeline of key Cooperative Extension Service dates

1862	*Morrill Land Grant College Act*	grants land to Colleges (1862 colleges) to be sold to fund the development of universities
1890	*2nd Morrill Act*	formalizes direct appropriations to the 1862 public land grant colleges and creates the 1890 colleges
1872-1887	*State College Farmer Institutes*	create early outreach efforts to link farmer with state colleges
~1880	*Connecticut station*	creates successful partnership between farmers and research scientists investigating fertilizer company fraud
1887	*Hatch Act*	creates agricultural research stations funded by the federal government under jurisdiction of state colleges
1903	*Early, field-based extension agents*	Knapp builds his vision of country agents working directly with farmers, on demonstration farms, and in their fields to address cotton boll weevil
1910	*Commission on Country Life*	Roosevelt's commission into rural livelihoods calls for increased education and access to information supporting sanitation, diet, household care, garden and community organizations
1914	*Smith Lever Act*	creates the cooperative extension service
1914-1918	*WWI*	CES grows considerably supporting wartime production of wheat
1920	*National Farm Bureau Federation*	creation of a national lobbying organization that was contentiously funded and supported by CES
1918-1940	*Intra-war years*	CES supports rollout and enrollment of numerous agricultural policies (Agricultural Adjustment Act and Caper Volstead Act) and New Deal programs (Soil Conservation Service, and the Tennessee Valley Authority)
1940-45	*WWII*	CES expands again, supporting national war effort in 1) coordinating farm supplies and marketing and 2) supporting rural nutrition and rationing
1945-1980	*post-WWII*	CES supports adoption of green revolution technologies, establishing the linear extension model based on Roger's (1962) diffusion of innovation theory
1970-1990	*Modern CES critiques*	Hightower publishes *Hard Times, Hard Tomatoes* and critiques of the CES surface around the rural livelihoods and shrinking number of farms
1990-2010	*Alternative extension models*	rise of alternative approaches to the linear model of extension: agroecology, multiple source innovation model, farmer first, farmer field schools, agricultural innovation systems, political agronomy

education at the time. Stephens and Roderick (1975) in analyzing the major traditions of western universities identified three main influences. First, the English model, was mostly elitist, stressing the needs and development of the individual student and largely dismissing practical insights of post-renaissance "new" science. Second, the German model, or *Wissenschaft*, was empirically based, subject matter-oriented, and distinct from the English model, was explicitly employed in service of state needs. Lastly, the Scottish model was perhaps more democratic due to a poorer demographic, reaching people at home, and emphasizing research and the new sciences as their population served the growing needs of Britain. Thus, while there were private colleges that tended to follow the English tradition, the Morrill Act was established mainly for the general population and to serve the "cultivators of the soil, artisans, mechanics, and merchants" (Graham, 1990, p. 22). While this call to service would not be institutionalized until the Smith-Lever Act and perhaps not fully embraced until WWI, the Morrill Act did represent a distinct turn in education from previous traditions (McDowell, 2001).

The agricultural colleges struggled early for relevancy, and close to 20 years after the first Morrill Act passed, only three colleges had more than 150 students. They taught science and subjects in classical established tradition, but they simultaneously attempted to justify their existence to farmers. This proved somewhat problematic as the colleges lacked tested agricultural knowledge and had little to teach farmers. Furthermore, it was nearly impossible for farmers to enroll in the colleges and leave behind their farms (Graham, 1990).

During this phase, the new colleges grappled with a central question for the practice of agricultural research, education, and outreach that would continue for decades to come: was agricultural research the province of the farmer or the scientist? In the mid 19th century, farmers widely considered themselves the only ones capable and knowledgeable enough to perform meaningful research. In farm journals and meetings, farmers often "maintained that research was their responsibility and lambasted, ridiculed, or ignored the hardy handful of Americans who continually disagreed… [In the view of farmers,] non-farmers seemed to lack the character necessary to pursue agricultural research" (Marcus, 1988). Indeed, those farmers who might be swindled into believing the advice of non-farmers, many of which had attended European scientific schools, were labeled "book farmers." While agricultural research was taking place during the mid-1800s, this research was distinctly separate from the private farming enterprise, such as conducting surveys, and ensured that it did not "provide individuals with unwarranted competitive advantages" (Marcus, 1988).

Farmers themselves had definite ideas about what the land grant colleges should be doing. They advocated for vocational training, exhibiting and cataloging the best practices of successful farmers and, in turn, teaching their children to be better farmers. Instructional topics could be farm management, farm machinery, or farm accounting. Not to be forgotten, was a requirement for manual labor, necessary to maintain the character for the future farmers (Marcus, 1986).

The colleges found themselves in a particular dilemma. They had a clear mandate to serve the farming population and scientific training to put to use, but few farmers wanted to engage with these trained academics. These academics, of course, had their ideas about their purpose and importance in serving the agricultural population, if only it would allow itself to be served. Of note is that farmers and scientists did not fundamentally disagree on either the mandate of the colleges, to serve agriculture, or that there was a need for a more modern farmer. The farmers themselves understood the need to systematize and improve the practices of a multitude of practitioners. However, the scientists, many trained in European schools, had more settled ideas of how that service and modernization might take place. Many argued instead that agricultural science was explicitly the province of the trained researcher. That the farmer, without specialized training, could not understand the intricate concepts of chemistry and, instead, was to utilize the principles that the scientists had derived. This produced two parallel rationalizations for the agricultural colleges in direct opposition to the farmers' vision. Some argued that the role of the colleges was to create a new “practical farmer” that would learn the principles of agriculture, again which only the scientist could deduce; vocational training would take place on the farm. The second, and more divisive rationalization, was that the purpose of the colleges was actually to train future researchers, who would further the scientific enterprise (Henke, 2008; Marcus, 1986; McDowell, 2001).

The discussions between these opposing ideas about how the practice of agricultural education would be carried out could be described as little less than warfare. The state colleges attempted to justify their science by creating farmer institutes, where they would gather farmers to make their case. These institutes manifested in a diversity of forms, from single meetings to multi-week seminars. At one point, 71 trains that had been converted into learning exhibits, traveled across 28 states, reaching almost 1 million people (Graham, 1990). While some undoubtedly accepted these outreach efforts, many farmers also resisted the concept, claiming that the "college professors confused who ought to be talking and who should be listening" (Marcus, 1986). Farmers crafted their own, parallel, farmer gatherings specifically excluding non-farmers, attempted to take over the existing institutes, and continued to rely on the growing number of farm journals. The battles continued over college curriculum, appointments, and in state legislative bodies over funding (Henke, 2008; Scheuring, 1988).

One of the few areas of common ground, between farmers and scientists, was found in the first state-sponsored research station, the Connecticut Station. While the scientific community continued calls for stations in the German model, where scientists would devise the basic functions of agriculture, the Connecticut station made an implicit trade-off; the scientists would emphasize technical skills in place of investigative skills. The farmers would devise the questions that the scientist would answer. The station used the issue of fertilizer fraud to serve its community best. Given the large fertilizer trusts of the time, farmers needed help assessing what was real fertilizer and what was false. The station utilized the chemists' skills of assessment and thus served the farmers' needs. Seeing the success of this station, other colleges attempted to justify their stations. However, farmers still treated the colleges with "suspicion, dissatisfaction, or disgust" (Marcus et al., 1986), and most legislative attempts failed.

This was the tenor of the times leading up to the 1887 Hatch Act, which would establish federal funding for agricultural research stations, and attempted to solve the conflicting visions of the times. The debate around national legislation centered on three competing value systems, the researchers' scientific values, the farmers' utilitarian values, and some legislators' strict constructivist. The constructivists attempted to adhere to strict notions of the constitution, ensuring that the federal government did not extend its jurisdiction nor create a potential concentration of power (Schweikhardt and Bonnen, 1986). The Hatch Act thus sought to reconcile these values and created agricultural research stations with an explicitly applied orientation, which, while being funded by the federal government, would be under the specific jurisdiction of the state colleges. If the Morrill Acts implied serving the general population through a focus on the "agricultural and mechanical arts," then the Hatch Act codified this desire to reach a broader constituency. The Hatch Act emphasized that the purpose of research at the stations was, "the development and improvement of the rural home and rural life and the maximum contribution by agriculture to the welfare of the consumer" (Hightower, 1972). However, given the inability of the state colleges to deliver meaningfully to the people under the Morrill Act, some saw the Hatch Act as a clear indication that the colleges had determined to “solve basic problems set by the academicians themselves” (McConnell, 1953, p. 22).

The birth of extension

Amid these debates, the idea of extension began to build. While successful in some senses, the farmer institutes still limited involvement. There was broad recognition that whatever the method of outreach, there were significant challenges, including traveling long distances to gatherings and the digestibility of group lectures. Additionally, even while the early 1900s are thought of as the golden age of American agriculture, with reasonable farm prices and relative political stability, there was also the clear recognition that more may be required of agriculture in the coming years. The urban population continued to grow, and the farm population shrunk to 1/3 of the national population, now 1/3 of the workforce. As one farm institute specialist remarked: “if no better system of dissemination of agricultural information is devised than that which has existed in the past it is manifest that agriculture in this country will progress far too slowly to meet the demands for food and clothing by our rapidly growing population” (Graham, 1990). Most agricultural colleges took up extension by essentially copying the existing institute model, but it was not until the outbreak of boll weevil in cotton that extension, as we know it today, took form (Graham, 1990).

Seamann A. Knapp, whom many consider the father of the Extension service (table 3.1), was initially employed as the "special agent for the promotion of agriculture in the south" to support cultural practices to control the boll weevil. Having worked as a farmer, a professor of agriculture, and a college president, Knapp's experience led him to believe that it would be working with farmers, working on their fields, that would see the most significant impact. He is widely credited with the saying: "What a man hears, he may doubt, what he sees, he may possibly doubt, but what he does, he cannot doubt" (Graham, 1990). In 1903, as the boll weevil decimated cotton crops in the south, businessmen funded Knapp's vision of country agents working directly with farmers, on demonstration farms, and on their fields to solve the problem. Knapp's vision led to successful control of the boll weevil and extended to many county agents throughout the south.

Simultaneous to Knapp's experiment in extension was President Teddy Roosevelt's Commission on Country Life. When the committee published its assessment of the rural population in 1910, it exposed some genuine needs of rural residents. Eventually, it called for the increased education and access to information as well as rural activity that would bring support in sanitation, diet, household care, gardens, and developing community organizations. On the issue of agricultural l education, the commission was quite clear, agricultural extension was necessary, and "without which no college of agriculture can adequately serve its state" and that the current effort was "on a pitiably small scale as compared with the needs" (Graham, 1990, p. 44). Highlighted in the study was the need to keep the effort grounded in the communities, to be “simulative” rather than “mandatory” and “develop native resources, not only of material things, but of people” (Graham, 1990, p. 45). The impact of the commission, coupled with the success of Knapp's work and an admission of a need for increased future production, led to a growing call for a national extension program.

However, this growing momentum was not without its detractors. The work of Knapp had primarily developed in the south and was supported financially by both private local business and federal funds via the USDA. This flew rather directly in the face of the state college system, which had been operating in the northern states and had relied on the farmers' institutes, exhibitions, and group meetings. While many within the college system acknowledged the need for a more hands-on approach, they also feared the added burden of face-to-face extension work as well as the potential for the federal government to overstep the state's jurisdiction in the administration of educational programs.

However, more than merely an administrative power struggle, some worried about the potential outcomes of such legislation and who it may determine the future agenda for extension. Many of the supporting arguments in Congress were grounded in the increased levels of production. Further investment would, undoubtedly create more efficient farm production and ensure ample food supply, while giving farmers a larger profit margin. However, others worried that increased production would eventually lead to decreased prices and falling profits, perhaps only benefiting the most successful farmers (Graham, 1990). Here, again, is the question of how to serve the rural population best: should Congress help improve production to integrate farmers into the market economy that had already resulted in significant declines in the farming population, or was it to serve the people themselves, in maintaining a rural livelihood? Indeed, critics of Knapp's work point to the private business interests that were instrumental to its genesis, and that expanded exponentially as the "movement" for extension grew. Much of the success of Knapp's work was not in ensuring the viability of all farms but rather ensuring the steady stream of products, in this case, cotton, to an increasingly industrial economy. In doing so, Knapp's work, the foundation of extension, was centered around bringing farmers into compliance with market imperatives, rather than buffering them from the market effects. It is of particular note that this extension work, primarily at the service of industry, was labeled education. Indeed, McConnell argues that this was a deliberate act to depoliticize the extension farmer associations in particular opposition to more politically-minded organizations. Institutions like the grange and the farmers union had a more direct connection with the populist movement of the late 19th century, a movement that neither business nor the traditional political parties much wanted to reexperience.

Furthermore, there was ample evidence that not only was early extension serving the wealthiest farmers, but the experiment stations were doing so as well. Thus despite the intention to serve "the development and improvement of the rural home and rural life" many stations were only working with the most productive farmers and by 1911 openly admitted that "it is undoubtedly the duty of our institutions to render service to industry" (Hightower, 1972).

Additionally, some viewed the creation of a national extension service with the same worry about the potential consolidation of power that had emerged during debates over the Hatch Act and the Morrill Act before it. The Dean of the Illinois College of Agriculture, in the proceedings of the 1913 Association of American Agricultural Colleges and Experiment Stations, stated:

> "The inevitable result of the department's concerning itself intimately with local conditions is to attract the attention of unscrupulous politicians, who will find therein a powerful means of advancing their own personal interests. Given four or five thousand local agents scattered among the farmers of all the congressional districts and under the practical control of a department which depends for its very life upon annual appropriation by Congress, all operating under the interlocking scheme of the new Lever bill, and we should have constructed and at work the most gigantic political machine ever devised. That it would be used, there is abundant evidence already at hand" (McConnell, 1953, p. 35).

This statement would prove prophetic as farm policy developed over the next 50 years.

Despite ideological reservations, there was consensus on the need for education and rural services, while the mechanics had to be worked out. Given the territorial battles that were already in evidence between the southern and northern forms of extension, a compromise had to made around control and autonomy. Smith and Lever proposed that work would be agreed upon by USDA and state colleges, institutionalizing cooperation. States would submit work plans for the allocation of resources, but the states would have near-total control of the application of those plans. The states would manage the county extension agent who would work at the farm level, again with a high degree of autonomy. Throughout the debates, there was evident worry about an overly controlled county agent, who would not be able to serve the needs of localities. Supporters of the CES see this compromise as the beginning of a uniquely integrated and autonomous organization. Meanwhile, critics, such as McConnell, contend that this compromise, national in scope but with significant autonomy, would leave the CES exposed for easy cooptation. Thus, the particular structure can be viewed not so much as the effect of meaningful compromise, but rather as the intended result of powerful business interests that codified in national legislation the perpetuation of a program that would continue to wrestle agriculture from the people, and into the hands of the industrial process that would subjugate them (McConnell, 1953). And yet, the potential for local control also codified extension’s flexibility and positions it uniquely for rapid change.

In 1914 the Smith-Lever act was passed, and extension was born. President Wilson commented that it would "ensure the retention in rural districts of an efficient and contented population."   Its purpose was "to aid in diffusing among the people of the United States the useful and practical information on subjects relating to agriculture and home economics and to encourage the application of the same.” Agreements were that all extension work would be carried out by state colleges of agriculture, with joint appointments with extension and the college.

There was considerable trust-building that had to occur with book-learned young agents and established farmers. As a result, extension work was initially rooted in collective meetings and groups. County agents understood the need to meet with growers collectively to multiply their efforts, have close contact, and to provide a clearinghouse for information. Eventually, these local organizations took on the name of the farm bureau. Some of the first requirements of new agents were to create farm bureaus with considerable help from state offices. Early on, there was financial support for these farm bureaus, and in some instances, they were designated as legal representatives of county governments.

While extension was slowly establishing its infrastructure and network, it wasn’t until WWI that it endeared itself to the nation. As the war progressed, extension bloomed under a unified mission to push for wartime food production, mainly of wheat, and played a pivotal role in mobilizing equipment and organizing resources to achieve these goals. As a result of this utility and success, county ag agents increased from 928 in 1914 to 2,435 in 1918, with all fifty states employing agents in 1917 (Graham, 1990).

While those in the CES lauded this utility in the war effort, critics highlighted the critical distinction between the CES' educational mission and a more commercial market-oriented agenda (McConnell, 1953). Indeed, both during the war and immediately after, county agents found themselves in the role of collectively buying supplies and marketing products for farm bureau members. In some instances, the administrative tasks of running the bureaus were delegated to the county ag agent.

There was undoubtedly a rationale to this emphasis, given the private local funding of the farm bureaus and county agents. However, while the farm bureaus were intimately tied to the birth and growth of extension and often represented some farm interests in the county, they were never intended to be representative organizations. The farm bureaus often required high relative annual memberships and were sometimes expressly exclusionary in their admissions. Echoing the criticism of the commercially integrated nature of Knapp's early work, critics again pointed to the role the CES was playing in serving the most affluent, market-oriented farmers, at the expense of smaller, independent-minded growers (McConnell, 1953).

As the farm bureaus' found success in commercial promotion via collective action, there was an inevitable evolution into the political realm. As the nation readjusted to prewar purchasing with farm prices declining and agriculture heading towards depression, there was an additional need for the farm bureaus to pivot heavily to political mobilizing in the 1920s. Local farm bureaus eventually federated into a national organization, which became a loud voice for legislative and economic lobbying. The Farm Bureau Federation (FBF) played a massive role in mobilizing the "farm bloc," a group of congressional leaders committed to agricultural support policies. Together these two groups were influential in both securing additional funding for extension that, in turn, was expected to mobilize farmers for the bureaus and for implementing the Capper Volstead Act and the Agricultural Adjustment Act in the 1920s and 1930s (McConnell, 1953).

As the Farm Bureau Federation (FBF) (table 3.1) became more engaged in political lobbying, there was apparent confusion about the management of the county agents. Congressional members were confounded by a national non-governmental lobbying organization, the FBF, that was heavily supported by government funds via the integrated support role the county agents played. Indeed, while county agents were initially supported by local private funds, by 1924, public funds accounted for 93% of all funding. After several congressional hearings in 1921, legislators established strict boundaries between what role extension agents could play in local farm bureaus (Graham, 1990).

In addition to concerns of Farm Bureau and commercial cooptation for the agenda during this early stage of CES growth, there was also tension about federal overstepping of jurisdiction. The success of CES in implementing the national war effort further set the stage for the agency's role in other national programs. As the nation struggled to support agriculture post-WWI and the whole of the nation during the great depression, it relied heavily on the extensive network that the CES service had established during the war. As a result, the CES played a crucial role in the rollout, enrollment, and implementation of not only agricultural policies, the Agricultural Adjustment Act and Caper Volstead Act, but also numerous new deal programs, including the Soil Conservation Service, and the Tennessee Valley Authority (figure 3.1). The CES grew in personnel and funding during this period, but there was also considerable tension as state governments and LGUs worried about the overreach of the federal government. While the federal government eventually agreed to work with the states, the precedent for national influence on extension programs was further entrenched (Graham, 1990).

In thinking about the dual threats of commercial interest via the farm bureau and federal-state jurisdictions issues, B.H. Cocheron, the head of the UC extension service, perhaps encapsulated them best, “during the AAA extension has acted as chore-boy for the federal government and for the farmers’ organizations… The nation has given the credit to the bureaus that have been helped and not to the great outstanding agency, agricultural extension, which has done the helping” (McConnell, 1953, p. 83). While agreements were made with both entities, the tensions around industry service and federal jurisdiction had surfaced again and would continue to surface through WWII and beyond.

Extension again grew during WWII, both in funding and size, as it worked to mobilize support for the national war effort. Emphasis again shifted to coordinating fertilizers, labor, tractors, and other equipment to meet the growing needs of the country. However, they were also enlisted to promote adequate nutrition, household machine maintenance, and food rationing. Similarly, as the nation moved into the post-war period, extension continued its service role, supporting veterans returning to farm.

Simultaneously, extension worked to support new technological adoptions of chemical fertilizers and pesticides, hybrid seed, and newer uses of mechanical power. During the 1950s combining all of these technologies, production per acre increased by 80-100% (Graham, 1990). The practice of technological transfer for economic gain that began in the post-war era, is perhaps the most common conception of extension. While generally accepted, it is essential not to lose sight of the early critique of this work, namely that it anchored the farm within a market structure. This anchoring tied grower prices to distant market forces and simultaneously coupled their production to increasingly costly inputs. This integration within the market economy was, again, in strict opposition to the notion of 19th-century agrarianism, which was insistent that power must be circumscribed and limited and that only through this limitation would one achieve independence and freedom within a democracy. Thus, while there were early efforts to restrict the influence of markets on producers, the current ubiquity of market integration has ostensibly built that power into the conception of agriculture today (McConnell, 1953).

Changes for extensions

As extension grew into the 80s, change was clearly on the horizon. Conversations about the environment and equity were raging across the country, and critics were curious about how the CES agenda and priorities would respond to the concerns of Silent Spring and the evident racial disparities in who was receiving service. Further, investigative journalists focused on federal budgets, and a widely read column in Readers Digest highlighted the CES as one of "Uncle Sam’s Ten worst taxpayer rip-offs.” National level debates emerged about the CES mission, efficacy, clientele base, and overall relevance (Johnsrud and Rauschkolb, 1989). Several federal reports were commissioned and completed addressing these issues.

The main thrust of these reports was the question: given the general decline of rural and farm populations, how could a federal program with a budget of $800million still be relevant? Indeed, in the 80s, only 3% of the population was farmers, with the rural population shrinking to 30% (Warner and Christenson, 1984). In addressing this question of relevancy, an only slightly lesser concern was should the clientele be traditional rural and farm populations, or should it move towards more socially oriented programs that arose from the radical upheaval in the 60s and 70s.

While some of the reports called for a broad, flexible statement that would allow the CES to adapt, others recommended a renewed focus on food and fiber producers. Simultaneously a 1981 GAO study concluded that if the CES was going to serve people other than farmers, then the funding based on rural and farm numbers would have to be adjusted down, and if it was only going to serve farmers, then the current level of funding could not be sustained. Either way, budget cuts seemed imminent (Warner and Christenson, 1984).

As expected, there was plenty of response to these critiques from inside the CES. While proponents cited the relative success of American agricultural productivity, many also highlighted its unique nature as an autonomous organization, with its unique funding structure and particular responsiveness to local conditions, with nearly 2/3 of the staff located at the county level (Johnsrud and Rauschkolb, 1989). The debate has not yet found public resolution and continues to fester today. The CES is still incredibly broad, covering programs including nutrition education, gardening, energy, and rural development while continuing to work with food and fiber producers. However, the budget has been whittled away over the past almost 50 years, now 50% of the 1974 level (Wang, 2014).

Today, the central questions for extension, who to serve and how best to serve them, are still being debated. A significant thread of contemporary criticism, that has been present since the inception of extension – does serving industry serve the farmer, and the public – continues today. Hightower, in Hard Tomatoes, Hard Times (1972), made current the historical concerns McConnell voiced 20 years prior. Hightower takes to task what he describes as the land grant complex (LGC), the combination of the land grant universities and state agricultural experiment stations (SAES), for an unrelenting accommodation of agribusiness interests at the expense of farmers and rural America. Hightower's sprawling account of the land grant complex indexes multiple occasions at which the LGC has skirted its responsibly to the rural population citing an organizational structure that incentivizes collaboration for personal gain and the resulting technological outputs that serve the profit motive above consumer health, rural livelihoods and small farm viability:

> *"land grant researchers are using tax dollars to concoct managerial schemes and to design technological systems that will send millions more packing off to the cities. Tax dollars buy new tinker toys for agribusiness, misery for migrants, death for rural America, and more taxes for urban America. All in the name of efficiency. Except for*

> *agribusiness, land grant college research has been no bargain. Hard tomatoes and hard times is too much to pay"*

Hightower calls for a commitment to keeping people on the farm, "putting the research focus on people first – not as a trickle-down afterthought (Hightower, 1972).

Others echo Hightower's concerns in publications that explore the industry-university relationship, both in a contemporary historical context, while also looking forward to new challenges that may arise (Busch and Lacy, 1988; Busch and Lacy, 2019; Buttel, 2005; Buttel and Busch, 1988; Buttel et al., 1986). While this work centers mainly around the advent of biotechnology, their findings apply to broader conceptions surrounding the LGC. Buttel et al. (1986) deepen Hightower's expose, by expressing the subtle changes in the industry-university relationship, how they have shifted from a more direct relationship between researchers and industry to more broad university-industry partnerships and how these relationships restrict the traditional academic flow of information, either because of licensing clauses or by researchers themselves who see benefits in monopolizing information. Indeed, Buttel et al. (1986) point out that the relationship that Hightower and McConnell criticized – one of agribusiness' direct or indirect influence over research and extension work – is also changing to accommodate a new division of labor. Buttel and Busch (1988) also highlight the shift in SAES priorities from applied research to more basic research, especially surrounding biotechnology. This is a result of both federal pressures to use the SAES to support the national position in global biotechnology research, but also represents the increased role of private industry in food and agricultural research (Buttel and Busch, 1988). They estimate that in 1988, private industry produced almost 2/3 of the research in this area. Indeed, biotech firms, who were not only funding university centers, but sometimes buying departments outright, were increasingly looking to public research for basic research around genetics that could support their product development. This parallels the experience of plant breeding. Historically, university derived plant lines were a way to control the quality of seed and hybrids. However, there has been increasing pressure for those departments not to produce lines that would compete with commercially viable varieties (Buttel et al., 1986). Thus, critics describe a division of labor, where industry has increasingly co-opted the research endeavor where profitable, commodifying the creation of knowledge. This would be a startling development for McConnell or Hightower, that the LGC had moved beyond industry co-optation to industry irrelevance.

In addressing solutions, both Hightower and others call for solutions that have echoes in the past: widening the tent so that the LGC can be at the service of a broader constituency. While their suggestions point towards a more direct response to the criticisms around environment and equity that were prevalent in the 70s, the broad concern around inclusivity and service are still prevalent. While Hightower focused more on budgetary and programmatic transparency, Buttel and Busch (1988) called for a more interdisciplinary approach to research that would tackle the political nature of agriculture, navigating an expanding and diverse clientele and negotiating the criteria for success. They imagined that in the era of private commercial research, the public university may need to define itself around research agendas without direct commercial application, but still vital to the health and welfare of communities (ibid.). This would be an interesting return to the origins of the CES that explicitly drew these boundaries, and one that would largely be supported by the autonomous institutional structure.

Globally, this process has evolved into the privatization of extension activities. Given the commercial application of existing extension services and acknowledging the current shortcomings of extension: a lack of user engagement, declining public funding, many believe that the private sector is more capable of allocating resources efficiently (Kidd et al., 2000). These efforts have taken various positions in the matrix of public/private funding/provision, taking shape as a full or partial fee for service as well as publicly subsidized private extension (Rivera and Sulaiman, 2009). Concerns are raised over the distinct differences in agricultural systems in the North and South, with generally much more supportive infrastructure, credit, markets, processing, input provision, in the North, allowing more incentive for those growers to utilize extension services. Similarly, where agriculture is struggling, a lack of disposable income will prevent the acquisition of services, especially when the additional cost of food and health care will take priority (Lindner, 1993). Further, while it is understood that shortfalls will exist in providing services for strictly environmental information or innovation for social good, most scholars admitting there will need to be a pluralistic approach (Rivera and Sulaiman, 2009). However, to date, most privatized extension systems have tended to de facto forgo this plurality (Rivera and Sulaiman, 2009).

Alternative extension models

These debates around the CES agenda and who would control it, were paralleled by experiments with alternative forms of extension practice that might begin to address some of the disconnect between formal extension and broader rural livelihood concerns. There were numerous attempts to center people in the process of agricultural research and extension that came through multiple frameworks: agroecology (Altieri, 1989), multiple-source innovation model (Biggs, 1990), farmer-first (Chambers and Thrupp, 1994), or agricultural knowledge and information systems (Röling, 1996), all began to apply a more participatory methodology to the research process. These frameworks position themselves in contrast to Rogers' (1962) "diffusion of innovation" theory, a robust extension framework that evolved primarily out of the US institutional context, notably the spread of hybrid seed in the 50s, and is characterized as a linear relationship between researchers, extension agents, and farmers. Also called the linear model, this framework centers innovation in the research domain, with extension playing a role to both disseminate these innovations to farmers in one direction, while also informing researchers of farmer needs in the opposite direction. However, while this system acknowledges feedback loops from farmers, people-centered frameworks place an even greater primacy on that input. The multiple source innovation model and farmer-first frameworks, including the Farmer Field Schools (Waddington and White, 2014), are perhaps closest to the linear model in that they acknowledge that innovation happens on the farm level and refuted the idea that science and technology development could be apolitical (Biggs, 1990; Chambers and Thrupp, 1994).

Agroecology took these farmer-centered models a step further expanding research to explicitly underscore the imperative of the ecological relationships in agricultural systems. Some proponents went further emphasizing the importance and necessity of radical political reforms that allow farmers to not only participate in the innovation process but to control it (Altieri, 1989) creating strong echoes to the CES critiques of McConnel and Hightower. This more radical agroecology leans heavily on the concept of food sovereignty which focuses on a peoples' right to control and define their own food system especially in the face of an increasingly globalized food economy (Patel, 2009). Given the geopolitical forces that affect farmers worldwide (i.e. market based land reforms, commodity dumping, etc.) agroecology holds a stronger focus on political organizations over technological adaptations (Holt-Giménez and Altieri, 2013).

Agricultural knowledge and information systems (AKIS) also highlight some similar foci of the previous models, acknowledging the knowledge intensiveness of more sustainable agricultural systems, and the importance of multiple actors in the generation of ideas. However, it takes a broader, and noticeably less radical approach than agroecology, in addressing the complicated socio-political drivers of agriculture. Röling (1996) replaces the more politically charged language with a more theoretical tone, acknowledging that “our problems have less and less to do with instrumental rationality, that is, with person-thing relationships, and more and more to do with person-person relationships.” Thus, acknowledging that our agricultural problems may not be entirely technical in nature, but instead are concerned with ensuring that goals and outcomes are collectively addressed and understood. He calls for a constructivist approach to extension, which would center the extension agent as a facilitator, navigating the collective discourse that breeds innovation (Röling, 1996).

One of the more recent developments in extension theory is to extend the AKIS, to a more general agricultural innovation system (AIS), which borrows from innovation systems framework and focuses on institutional contexts that emphasize learning, and the capacity of all actors to learn, in generating locally adapted arrangements. It further broadens the scope of focus beyond the researcher-extension-farmer network to the policy and institutional level. In this context, some of the roles for extension include: "setting the innovation agenda; organizing producers and the rural poor and building their capacities; building coalitions of different stakeholders; promoting platforms for information sharing; experimenting with and learning from new approaches; and acting as a ‘bridging organization’ that provides access to knowledge, skills and services from a wide range of organizations, including research institutes” (Rivera and Sulaiman, 2009, p. 269). While both AKIS and AIS system invoke people and broader system influences on farmers and farm practices, the agenda of the research can easily be defined by broader economic constraints, limiting certain forms of innovation.

In understanding how to situate all the parallel and overlapping innovation systems in recent decades, Scoones et. al. (2009) provide a useful farming that again begins to bring conversations around both the agenda and practice of extension back to more populist roots. In revisiting the successes and challenges of the farmer first movement, the authors place innovations systems along a matrix of approaches, including analytical and normative work overlapped with mechanical and process-oriented foci. Using this framework, the authors assess the work of Farmer First as a normative mechanical approach. While they acknowledge the normative "pro-poor" focus, the extension approach was more mechanical in its technical application and failed to incorporate a broader food system impacts on grower decision making. AKIS and AIS system encompassed an analytical process-oriented approach that sought to utilize a broader systems approach addressing markets, supply chains, etc. to support farmers integration into the existing political economic model, but lacked a more normative, equity driven foundation. In response to what they saw as the failure of Farmer First to have a broad enough impact, the authors point towards a need for a more integrated normative approach that was both systems oriented and more inclusive of equity concerns outside of a purely economic development.

This more equity-driven systemic approach was not unique to the Farmer First group as it fits well with the more radical interpretations of agroecology and the populist critiques raised by Hightower. As there was a more widespread call for broader participation in agronomy there were parallel acknowledgements of the challenges of the global neoliberal project paired with a rise in popularity of environmentalism (Sumberg et al., 2012). This confluence of factors similarly led for calls for 'political agronomy' (ibid) and other more responsive approaches to extension and research. Similar among these approaches was an understanding of the temporal nature of the different approaches within systems. For example, there would be a place and time for more mechanistic approaches, but that the starting point was important in setting the agenda (ibid) and to ensure that shifts in approach did not represent a reformist capture of a normative and political approach (Holt-Giménez and Altieri, 2013), recreating the experience of extension in the 20th century.

Beyond the normative critiques of mechanistic research and extension, the early 21st century also increasingly understood the challenges that more ecologically based management systems posed to more formal, academic knowledge generation. There was compelling evidence that the heterogeneity of the agricultural systems, both for smallholder farms in the global south (Vanlauwe et al., 2019) and intensive organic and ecological systems in the global north (Shennan, 2008), meant that independent trials assessing single variables were less applicable. While these trials proved useful for more homogeneous systems with larger land bases and less complex cropping systems, they failed to support grower innovation and impact when there was high response variability. This required extension work in organic systems to be meaningfully different than more mechanistic models because the systems were more knowledge intensive and locally adapted (Padel, 2001). For these more complex systems, it was important to distinguish between action-oriented knowledge that focused on what happened, vs epistemic knowledge that explored how or why something happened (Hansson, 2019). This action-oriented knowledge is often generated via adaptive farmer trials that may change mid experiment if necessary. Again, there are important dimensions that epistemic knowledge can provide that more action-oriented knowledge would not, such as the ability to assess non-observable phenomena (i.e. soil microbes and pest/disease cycles) and to control confounding factors. Indeed, these are the particular types of questions that endeared extension to the farmer population, assessing fertilizer fraud and boll weevil outbreaks. However, the more integrated contemporary approach, also understands the need for the interplay between both adaptive, on farm-trials and more mechanistic research with each supporting distinct goals. With the advent of digital technology and new on-farm methodologies, there are increasingly sophisticated understandings of how this interplay could look that overlay rigorous epistemic knowledge methods on top of action-oriented, farmer led research (Lacoste et al., 2022). Further, experiments utilizing paired university grower partnerships have supported novel engagements between grower knowledge and practices with more epistemic questions and design (Shennan et al., 2016).

Essential to these newer ideas around agricultural extension and innovation is the concept of social learning. While there are echoes of this throughout the history of extension, especially in the early farmer gatherings that countered the early efforts of the state agricultural colleges, recent scholarship has highlighted the importance of how farmers learn and that the discursive process with other growers is instrumental to the application of new innovation systems. Thus, it is not only that growers assess what the environmental or economic outcomes of particular practices are, but that it matters who and how many growers are participating (Stone, 2016). This co-generation of knowledge is emphasized in agriculture given the complexity of systems and the sometimes-limited ability of formal research to balance the multifactorial variables and payoffs (de Janvry et al., 2016). As a result, this socially generated knowledge, i.e. what another grower is doing, is privileged over more academic knowledge generated from a formal research experiment (Stone, 2016). Indeed, Šūmane et al. (2018) argue that it is this social, or local, knowledge that is the everyday actionable knowledge, whereas more formal knowledge has more periodic applicability, arguments that would have sat well with early agriculturalist of the 19th century.

While Scoones' framework from 14 years ago still provides a useful tool to organize current approaches to agricultural extension today, there have been increasingly nuanced conversations about how the practice of extension might achieve more broad and sustainable goals. These nuances have centered around 1) a more politically rooted agenda for extension, 2) the interplay between more action-oriented and epistemic knowledge and 3) specifically the temporal relationship between these approaches. However, despite the extensive scholarship there is still strong momentum to continue the extension enterprise as it exists and double down on the linear model. These suggestions come primarily from the CES themselves and acknowledge that some small changes are needed in delivery and outreach, but that nothing fundamental needs to shift (Bull et al., 2004; Johnsrud and Rauschkolb, 1989). In California there have been recent efforts by the University of California Cooperative Extension (UCCE) to focus on citizen science efforts, but these have focused mostly on water quality, invasive pest and biodiversity, but little overlap with production agriculture (Meyer et al., 2021).

While there have not been system wide support of more participatory processes, there have been local efforts involving UCCE in supporting participatory methods. In particular the experience of a university/UCCE/grower partnership with organic strawberries, demonstrated the long-term, embedded relationships necessary to foster ecological innovation that meaningfully connected growers and researchers in the knowledge co-creation process (Kalaitzoglou et al., 2021). Given the important role of strawberries in the California Central Coast region, the inclusion of private companies and the strawberry commission were important in validating research and disseminating findings to impact broader acreage. Importantly the authors acknowledged this work transpired in the global north, in a highly commodified production system that can have more challenges realizing knowledge co-creation than regions that have more shared political motivations. While these embedded networks were less normative than some of the alternative extension models, they still played an important role in transitioning current production systems, with practices developed and disseminated now impacting 30-40% of organic California strawberry acres.

Recent Extension Efforts on OGNT in California

Within this context of highly commodified organic vegetable production in California it is worth reflecting on the experiences of a group of growers and researchers that investigated OGNT systems in the state. This group was organized under a Conservation Innovation Grant (CIG) program grant and ran for the years 2019-2022 with a group of over 40 growers and researchers that were working on reduced tillage systems in organic vegetable crops in California.

Early on in the process, as growers began to experiment within their systems, social learning was clearly the privileged method of knowledge generation. There was significant interchange between growers that resulted in different practices being adopted between farms. Given the relative newness of the practices there were plenty of examples of adaptive research where one practice clearly did not have the desired outcome (i.e. failed cover crop termination) and the plot was abandoned without further investment. All of these growers grew well over 20 different crops and had plenty of rotational opportunities to attempt experiments. As a result, year 1 and 2 was a highly adaptive approach with many different practices tried and abandoned.

However, through progression from year 2 to 3, more epistemic knowledge was desired. There was significant farmer driven questions regarding non-observable phenomena, namely fungal to bacterial ratios, tissue analysis, microbial community composition, and aggregate stability. These questions seemed to arise as growers encountered continued struggles with on-farm experiments and expressed a desire to understand what was hampering their success. These more rigorous experiments took shape in year 2 with some exploration of yield and soil dynamics, but in year 3 farms began to implement multiple replicated trials. One grower in particular had three randomized block trials occurring at one time assessing, fertility rates and tillage, tillage and crop rotations, and occultation impacts.

Thus over the course of the CIG project, a natural progression appeared to move from more informal knowledge systems to more structured investigations for further exploration. The flexibility that this type of project afforded, coupled with social learning, created an incredibly fast innovation space for many novel approaches to reduced tillage. This paved the way for more specific epistemic questions to be asked for particular practices as growers were able to hone their unique systems that catered to their own environments and businesses.

This was contrasted with the replicated field trial that was performed at UCSC in the same time frame. Because of the academic goals on the replicated field trial, the parameters of the trial were established early and could not be quite as flexible and nimble as the grower experiments. As a result, in only the first year, one CIG member commented on the lack of soil cover and in the system and the challenges that was likely to present. This would be a takeaway of the trial after two and half more years of experimentation.

Of particular interest in the distinction between action-knowledge and epistemic knowledge, was how the economic cost was distributed. For much of the project, the growers absorbed many of the costs of implementation; from the production costs, to yield losses, to costs of coordination. Given the ingenuity involved and the value to the grower community, this echoes previous research that outlines the constant experimentation of farmers (Stone, 2016) that often exists outside of more formal extension and research pathways (Cross and Ampt, 2017). While this is important from a policy implementation perspective, there is also the reality that this embedded cost actually limits the level of participation in these on-farm research experiments. Indeed, there was one of the three farmers that frequently remarked that they wished they had the time and resources to match the level of experimentation of the other farmers.

This then surfaces whether there was a meaningfully normative perspective during the CIG innovation process. In this instance, there was little equity motivation, and more prioritization of ecological processes (i.e. improving soil health or nutrient cycling) over a discussion of changing broader socio-political structures. This reflects the reality of these farmers' positions, each running economically successful businesses for over 4 decades. There is little incentive to disrupt the political economic drivers that underpin their businesses and livelihoods. This is observed in stark contrast to the more political motivations of farm organization in the global south, where these political economic drivers operate sometimes in direct opposition to grower livelihoods (Holt-Giménez and Altieri, 2013). Indeed, the development of new, and quite expensive tools was the focus of early conversations in systems design.

However, while there may not have been a direct livelihood rationale for a broader more political perspective in the context of the global north, there also appeared to be a significant lack of imagination to look outside of certain political economic framings to address the more privileged ecological considerations. Here it is useful to return to the history of conventional no-till system and the direct link to the development of fast acting short residence herbicides. Even though there was tremendous interest in the technology in the 1920s, it took almost a half a century to popularize with support from the chemical industry, synthetic fertilization, and equipment manufacturing. This process of agricultural innovation mirrors similar processes in agricultural mechanization. While often seen in hindsight as an inevitable conclusion of modernization, the process of mechanization was often a highly negotiated and nonlinear process that required commensurate changes in plant breeding, field preparation and processing to accommodate the new technology (Baur 2022).

As a result, there was no broader discussion about what a similar nonlinear process would look like for OGNT in CA. There were ideas discussed at the margins of conversations: seed breeding for crops that are specifically adapted to NT systems, cover crops that are bred for high biomass and early termination, but there was little exploration of the political economic constructions around land rents and production thresholds that defined economic viability (Guthman, 2000). In this way, as novel as the CIG group was, it also failed to address even more analytical process-oriented questions more typical in AIS.

Conclusion

The history of extension in the US and current conversations about the extension enterprise have repeated and overlapping arguments and rationales concerning who extension is for and how the work is done. Control of extension, while held early by a more populous rural farm population was contested within a economic landscape that was increasingly informed by global forces focused on commodity production. Through the early success of Knapp with export cotton, post WWII extension work with green revolution technologies and eventually the political machinations of the farm bureau, extension found a settled agenda supporting full market integration. However, this was a contested evolution, with both growers and politicians regularly emphasizing the need for rural support and unique legislative cooperative arrangements to ensure local autonomy and flexibility. From the Morrill acts to Smith and Lever, the legislative mandate for the CES was centered on more democratic, applied and relevant research and extension that would positively impact rural communities. Current critiques of extension have renewed these conversations, highlighting farmer knowledge and engagement, social learning, and a distinctly political orientation that would allow extension to stand above the economic constraints that defined its early development. And while these are meaningful critiques, they have focused more on the practice of extension and research, and less on the important role that the institution of the CES and the land grant universities play in the agenda setting for this important institution. Buttel argues that this may be a result of the irrelevancy of the LGUs, as research has become increasingly privatized, or a result of increased social movement focus on private approaches to agricultural change via consumer-producer relationships (i.e. the local organic food movement) or opposition to GMOs (Buttel, 2005). Still others argue that given the role that the CES played in developing the systems we have today it is unlikely that they would be able to meaningfully contribute to solutions (Röling and Wagemakers, 1998). However, given important institutional structures of the CES, particularly the degree of local autonomy and the reach of the organization, it seems important to revisit more focused critiques on the institutional agenda. This is especially true in the global north, where an acknowledgment of the political economic landscape is necessary in supporting the forms of extension that can impact significant acreage and provide meaningful dissemination pathways to active growers.

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