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# A Rainbow on the Farm: Specialty Crops for a Healthier Agroecosystem

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Agriculture in the United States remains highly concentrated in a few dominant crops—mainly corn and soybeans, which together account for 52.7% of total agricultural land in 2023, based on the USDA's Cropland Data Layer (CDL) dataset. This high level of monocultural pressure raises environmental concerns such as biodiversity loss, soil and water degradation, and greenhouse gas emissions (Power, 2010; FAO, 2021). Although it is difficult to isolate the specific contribution of monoculture to these environmental outcomes, numerous studies have highlighted the broader environmental footprint of modern agriculture. For example, Poore and Nemecek (2018) report that today's food system accounts for approximately 26% of anthropogenic greenhouse gas emissions and that agriculture is responsible for 78% of global ocean and freshwater eutrophication. In addition, according to the FAO (2011), agriculture accounts for 70% of global water withdrawals (49% in North America).

While there are several agricultural and conservation practices that can help mitigate these concerns, our focus is on one particular approach: introducing and promoting specialty crops to enhance crop diversity and provide both agroecosystem and economic benefits.

## Specialty Crops: Their Role, Patterns, and Potential Benefits and Risks

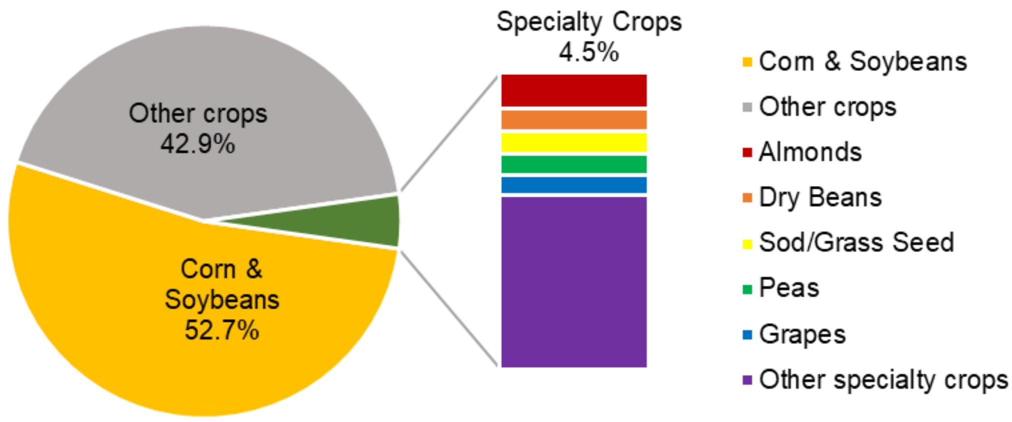
What exactly are specialty crops? According to the Specialty Crop Competitiveness Act, amended to the Farm Bill, specialty crops include fruits and vegetables, tree nuts, dried fruits, horticulture, and nursery crops (USDA-AMS, 2025). Figure 1, based on the 2023 CDL data, indicates that the top five specialty crops, based on acreage, are almonds (12.0% of total specialty crop area), dry beans (7.8%), sod/grass seed (7.6%), peas (7.0%), and grapes (6.9%). Together, these crops account for 41.3% of the total specialty crop area. Overall, specialty crops make up about 4.5% of the total agricultural area in the United States, yet they generated $84 billion in cash receipts in 2022, accounting for about 15% of total agricultural cash receipts (USDA-ERS, 2024).

There are, however, significant spatial differences in specialty crop cultivation. Figure 2 illustrates county-level data on the ratio of specialty crops to total farmland area and the average number of specialty crops grown from 2008 to 2023. Darker colors represent a higher percentage of specialty crops relative to the total farmland area (green) and a greater number of specialty crops harvested in the region (blue). Figure 2a shows that California, Oregon, Washington, and Florida have higher proportions of specialty crop area, whereas the Corn Belt region has a much lower specialty crop ratio. Similarly, Figure 2b indicates that West Coast states; Florida, northeastern coastal states such as Delaware, Connecticut, and New Jersey; and areas around Lake Michigan tend to have a greater diversity of specialty crops than other regions.

Climatic suitability, agricultural practices, market proximity, and historical land use all contribute to shaping these regional differences. For instance, California's climate is suitable for high-value specialty crops—such as almonds, pistachios, and walnuts (FarmTogether, 2025)—while the Corn Belt region prioritizes commodity crops due to scale and established processing networks (Karakoc et al., 2022). While specialty crops show significant regional differences, cultivating certain specialty crops can enhance soil health, increase biodiversity, reduce chemical inputs, and increase carbon sequestration. However, how effective and beneficial they are depends heavily on farming and production practices (Kim, 2016; Balis et al., 2024). For example, although almond production requires significant water use, efficient utilization of by-products can significantly reduce its overall carbon footprint (Kendall et al., 2015).

Adding specialty crops to enhance crop diversity is often promoted for environmental benefits, but impacts vary. In regions where a single high-value crop dominates, it

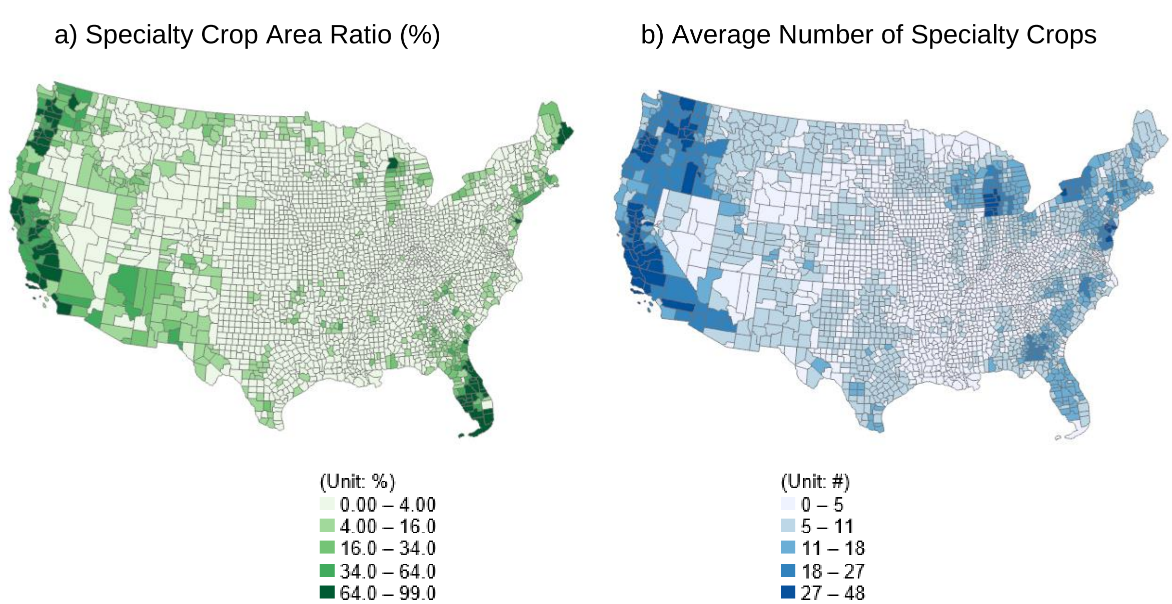
**Figure 1. Composition of US Agricultural Land: Major Crops and Specialty Crop Breakdown, 2023**




Source: Cropland Data Layers (CDL) from the USDA.

may pose unintended risks. In contrast, when used to diversify cropping systems, especially in areas heavily focused on commodity crops, specialty crops can support agroecosystem health and resilience. While specialty crops can contribute to agroecosystem resilience, they also present some potential risks. The expansion of specialty crop cultivation offers several advantages, including enhanced crop diversity and increased landscape resilience, along with improved agroecosystem services. However, challenges such as high water requirements for certain crops, like avocados, and the risk of monoculture due to the dominance of a single high-value crop must be addressed. Opportunities exist in the growing consumer demand for organic and locally sourced food, increased research and development funding for sustainable agriculture, and stronger policy support for crop diversification. Despite these benefits, the sector remains vulnerable to extreme weather events and faces the threat of farmland loss due to urbanization and competing land uses. These strengths, weaknesses, opportunities, and threats (SWOT) associated with specialty crops, particularly in relation to agroecosystem and economic outcomes, are summarized in Table 1.

**Figure 2. Spatial Distribution of Specialty Crop Production in the United States**




Source: CDL data from 2008 to 2023.

**Table 1. SWOT of Specialty Crop with Agroecosystem and Economic Outcomes**

| Strengths | Weaknesses |
|---|---|
| Enhanced crop diversification and landscape resilience<br>Improved agroecosystem services | High water requirements for some specialty crops (e.g., avocado)<br>Monoculture risk with the dominance of a single high-value specialty crop |
| **Opportunities** | **Threats** |
| Growing demand for organic and local food<br>Increased R&D funding for sustainable agriculture (e.g., USDA, 2024)<br>Stronger policy support for crop diversification | Vulnerable to extreme weather events<br>Farmland loss due to urbanization and alternative land uses |

**Notes:** Source: Balis et al. (2024), Kim (2016), USDA (2024).

## Beyond Monoculture: How Crop Diversity Enhances Ecosystem Services

Different types of specialty crops are grown across various regions, influencing overall crop diversity. The next section will explore how crop diversity is defined and measured.

### *Crop Diversity: Definition & Measurement*

Crop diversification simply refers to growing more than one type of crop in a given area. However, crop diversity can encompass different aspects. It may involve growing different crop species (species diversity), cultivating multiple varieties within the same species (varietal diversity), or maintaining a broad genetic pool within and across crop species (genetic diversity) (Aguilar et al., 2015). The term can also refer to various plants within an agricultural field (field diversity), including crops and noncrops. On a broader scale, it may extend to different types of land use across a landscape or region, such as forests, agricultural fields, and wetlands (land-use diversity). In this article, we focus on land-use diversity as a proxy for crop diversity because different land uses contribute uniquely to agroecosystem services, making this metric especially relevant (Le Provost et al., 2020).

So, how do we measure crop diversity? Is it as simple as counting the number of crops in a given area? This is not wrong, but it is only partially correct. Merely counting the number of crops is known as richness in ecology. Richness is an important measure of crop diversity, but it does not provide a complete picture, as it does not account for the distribution of each crop within an area. To fully capture the ecological and agricultural benefits of crop diversity, in addition to richness, evenness must also be considered. Evenness refers to how uniformly crops are distributed across the land. For example, consider two regions: Region A, where 90% of the land is planted with strawberries and only 10% with tomatoes, and Region B, where strawberries and tomatoes each

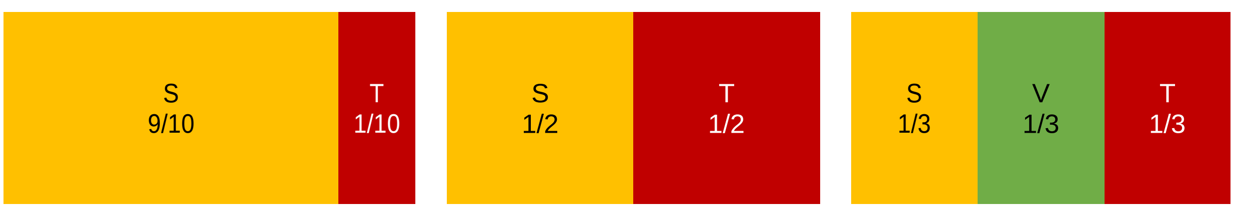
**Box 1. Crop Diversity Index**

(1) $HHI_{it} = \sum_{j=1}^{J} p_j^2$, $IHHI_{it} = 1/HHI_{it}$

(2) $SW_{it} = -\sum_{j=1}^{J} p_j \ln(p_j)$

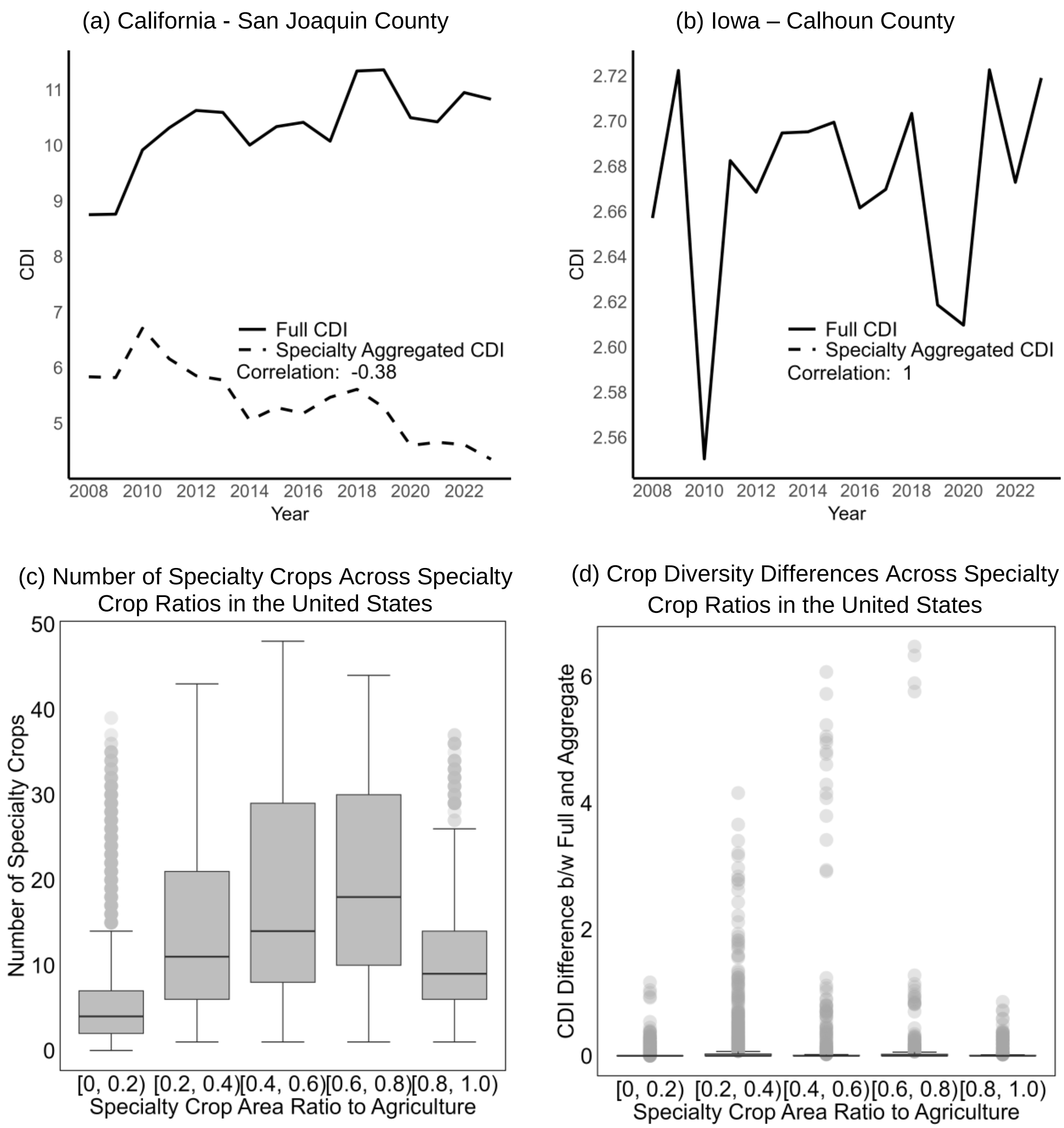
$p_j = \frac{a_{ij}}{A_i}$, $a_{ij}$: $j$th crop area in $i$, $A_i$: total area of $i$

S: Strawberry, T: Tomato, V: Avocado




| Region A | Region B | Region C |
|---|---|---|
| Number of crops =2 | Number of crops = 2 | Number of crops = 3 |
| IHHI = $1/((0.9)^2 + (0.1)^2) = 1.22$ | IHHI = $1/(2(0.5)^2) = 2.00$ | IHHI = $1/(3(0.3)^2) = 4.50$ |
| SW = $-(0.9\log(0.9) + 0.1\log(0.1)) = 0.33$ | SW = $-2(0.5)\log(0.5)$=0.69 | SW = $-3(1/3)\log(1/3)$=1.10 |

**Figure 3. Crop Diversity and Specialty Crop Distribution Patterns**




Notes: In Figures 3c and 3d, the horizontal line inside the box represents the median value. The box itself spans from the 25th percentile (Q1) to the 75th percentile (Q3), covering the interquartile range (IQR). The two whiskers extend to the smallest and largest values within 1.5 times the IQR from Q1 and Q3, respectively. Data points beyond this range are considered outliers.

Source: Cropland Data Layers (CDL) from the USDA.

cover 50% of the area (Box 1). While both regions have the same number of crops (2), Region B exhibits greater crop diversity due to its more balanced distribution (greater evenness). To quantify crop diversity while accounting for both richness and evenness, Box 1 illustrates two commonly used diversity indices: the Shannon-Wiener Index (SW) and the Inverse Herfindahl-Hirschman Index (IHHI). Several diversity indices are commonly used in agricultural and environmental studies. Among them, the Shannon-Wiener Index is widely adopted across disciplines due to its sensitivity to both richness and evenness. The IHHI, originally developed to measure market concentration, is often favored in applied economics for its simplicity and its emphasis on dominant crop types. Higher values indicate greater crop diversity in a given area in both cases.

**Table 2. Descriptive Statistics**

| Variables | Unit | Mean | Std. Dev. | Min. | Max. | *N* |
|---|---|---|---|---|---|---|
| Year | Year | 2016 | 4.61 | 2008 | 2023 | 49,735 |
| Crop diversity index | | | | | | |
| IHHI | Index | 3.00 | 1.38 | 1.00 | 11.74 | 49,735 |
| SW | Index | 1.29 | 0.45 | 0.00 | 2.8 | 49,735 |
| *Agratio* | Ratio | 0.23 | 0.25 | 0.00 | 0.92 | 49,735 |
| *Spratio* | Ratio | 0.05 | 0.13 | 0.00 | 1.00 | 49,693 |
| Water quality | | | | | | |
| Secchi disk depth | Meter | 1.72 | 1.82 | 0 | 19.5 | 18,957 |
| $NO_3$ | Mg/l NO3 | 5.55 | 6.65 | 0.14 | 32.6 | 17,986 |
| Fecal coliform | Cfu/100ml | 313.79 | 357.25 | 4.89 | 2,084 | 8,497 |
| Bird diversity (SW) | Index | 3.36 | 0.83 | 0.00 | 4.86 | 47,740 |
| Habitat quality | Ratio | 0.08 | 0.09 | 0.00 | 0.88 | 49,704 |
| Farm income | Million $ | 11,898 | 11,650 | 67 | 321,708 | 9,054 |

**Notes:** In the Crop Diversity Index section, IHHI and SW refer to the Inverse Herfindahl-Hirschman Index and the Shannon-Wiener Index, respectively. Agratio and Spratio represent the ratio of agricultural land to total land area and the share of specialty crops within total agricultural land (at the county level), respectively. Bird diversity index is also calculated based on the Shannon-Wiener Index. Habitat quality is an index generated by the InVEST model, ranging from 0 to 1. Farm income refers to county-level farm income per operation.

## *Crop Diversity and Agroecosystem Services*

Crop diversity offers numerous benefits—such as increased bird diversity, improved biological control, enhanced soil structure, and higher agricultural productivity—while also helping to alleviate the pressures of monoculture (Mäder et al., 2002; Di Falco and Chavas, 2006; Davis et al., 2012; Kennedy et al., 2013; Strobl, 2022). Government policies and programs also play a crucial role in supporting efforts to promote crop diversification. For example, the Environmental Quality Incentive Program (EQIP) and the Conservation Reserve Program (CRP) offer incentives for growing cover crops, rotating crops, and strip cropping, examples of crop diversity. Similarly, the Intergovernmental Panel on Climate Change highlights the benefits of crop-diverse farming practices in reducing greenhouse gases and improving environmental outcomes (Nabuurs et al., 2022). In the next section, we present and visualize our empirical results on the actual impact of crop diversity on agroecosystems.

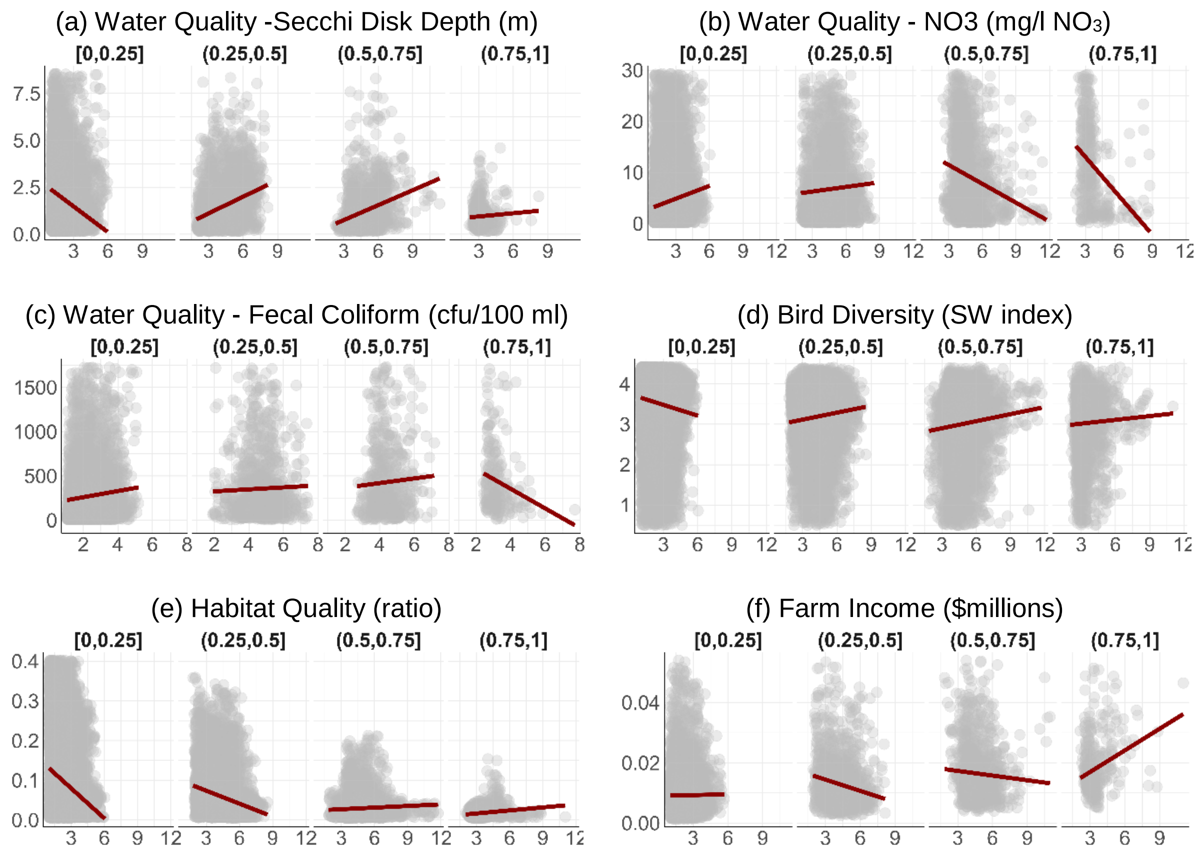
## *The Role of Specialty Crops in Enhancing Agricultural Diversity*

We employ the CDL dataset from 2008 to 2023 to investigate the role of specialty crops in enhancing crop diversity. Specialty crops can enhance overall crop diversity, but there are significant regional differences. In some regions, such as California, nearly 40% of the agricultural land is used to grow specialty crops, with an average of 20 different specialty crops grown at the county level among 62 possible types in our dataset. However, in Corn Belt states like Iowa, the specialty crop ratio is only 0.04%, and the average number of specialty crops is only 2. Figures 3a, representing San Joaquin County in California, and 3b, representing Calhoun County in Iowa, illustrate the difference between the two representative regions' crop diversity index and the contribution of specialty crops. The dashed lines in the graph indicate the crop diversity index (IHHI) when we aggregate all the specialty crops into one category (Specialty Aggregated CDI). In contrast, black lines indicate all crops separated crop diversity index (Full CDI). As we can observe from San Joaquin County in California (Figure 3a), there is a big gap between the Specialty Aggregated CDI and Full CDI, indicating specialty crops are highly diverse in this area. On the other hand, in Calhoun County in Iowa (Figure 3b), the Full CDI and Specialty Aggregated CDI are almost identical, without a significant gap between the two trends. Treating specialty crops as a single category does not significantly change the Full CDI in this region, suggesting Calhoun County in Iowa is extremely low in crop diversity.

Figure 3c shows that the average number of specialty crop varieties tends to increase as the specialty crop area ratio (relative to total farmland) increases across the entire United States. Specifically, the median number of specialty crop types increases gradually from four when the specialty crop area ratio is below 20% to 18 when the ratio is between 60% and 80%. However, after reaching the peak, the average number of specialty crop varieties declines to nine when specialty crops cover more than 80% of the agricultural area. This suggests that as the proportion of specialty crop areas increases, monoculture of specialty crops becomes more prevalent.

Meanwhile, in Figure 3d, the y-axis represents the difference between the fully separated CDI and the CDI where all specialty crops are treated as a single crop. This highlights the overall contribution of specialty crops to the crop diversity index (CDI), which appears minimal under the current state of US agriculture, as indicated by the median values being close to zero in the boxplot.

**Figure 4. Relationship Between Crop Diversity and Environmental and Economic Outcomes**




Notes: Farm income refers to the county-level farm income per operation. Each gray dot represents a county-level observation. The x-axis shows the crop diversity index (IHHI), where higher values indicate more diverse crop systems. The red line shows a smoothed local trend (LOESS). Each panel corresponds to a different quartile of agricultural land share (i.e., the proportion of farmland relative to total land area in the county). Each y-axis represents associated environmental and economic outcome measures.

Source: Cropland Data Layers (CDL) from the USDA, Water Quality Portal (WQP), eBird, InVEST, and USDA NASS Quick Stats.

Only a few outliers show a notable impact on crop diversity. However, a similar pattern to Figure 3c can be observed; the outliers' contribution to crop diversity increases as the specialty crop ratio rises, peaking at the 60%–80% specialty crop area level before declining in the final interval (80%–100%).

These regional contrasts and the variations across specialty crop area ratios suggest that the impact of specialty crops on crop diversity is highly context dependent. These findings highlight the need for region-specific approaches when assessing the role of specialty crops in agricultural sustainability and resilience. On the other hand, these results also indicate that the current agricultural structure of the United States is largely dominated by large-scale monoculture. Currently, specialty crops are not significantly increasing crop diversity in most regions. However, if future agricultural policies encourage more diverse farming practices and reduce dependence on monoculture, specialty crops could be strategically utilized to enhance regional crop diversity.

## *Empirical Analysis of Crop Diversity and Agroecosystem Services*

We investigated the empirical effect of crop diversity on agroecosystem services. The USDA Cropland Data Layer (CDL) is used to construct a crop diversity index. We incorporate water quality parameters—Secchi disk depth, nitrogen (NO3), and fecal coliform—obtained from the Water Quality Portal via the dataRetrieval R-package. We also incorporate bird diversity data from eBird, habitat quality metrics from InVEST, and farm income data from the USDA-NASS Quick Stats. More detailed and in-depth discussions about crop diversity's effect on water quality can be found in Park et al. (2023).

Before examining the relationship between crop diversity and agroecosystem or economic outcomes, we present descriptive statistics for the main variables. Table 2 summarizes key indicators, including crop diversity indices, agricultural land ratios, specialty crop land ratios, water quality, bird diversity, habitat quality, and farm income.

Figure 4 illustrates the relationship between crop diversity, agroecosystem services, and economic outcomes, grouped by four different ranges of agricultural land ratio relative to total land area. The x-axis in these graphs represents the crop diversity index (IHHI, the higher, the greater crop diversity), while the y-axis shows each environmental or economic outcome measure. For example, in Figure 4a, crop diversity does not positively affect water quality (as measured by Secchi disk depth: the higher, the better water quality) when the agricultural land ratio is small (under 25%). However, as farmland area increases, the effect of crop diversity on water quality becomes positive. A similar pattern appears with NO3 and fecal coliform; however, since lower values of these parameters (NO3 and fecal coliform) indicate better water quality, the apparent beneficial effect of diversity is reversed in the graphs. These findings suggest that increasing crop diversity may not significantly affect water quality in areas where agriculture occupies a small proportion of the land, since the negative impacts of agriculture are already relatively small in these areas. In contrast, when agriculture occupies a more significant portion of the land, diversification can help mitigate environmental impacts. As seen in Figures 4d and 4e, both bird diversity and habitat quality (where higher values indicate greater bird diversity and better habitat quality) generally exhibit similar trends. However, the patterns are not identical, with habitat quality (Figure 4e) showing distinct and consistent decline at lower agricultural land ratios, whereas bird diversity (Figure 4d) displays more variation across agricultural land ratios. Furthermore, Figure 4f shows that crop diversity can positively affect farm income in areas where agriculture dominates (over 75%). It may be because greater diversity helps distribute environmental and extreme weather event risks, makes it possible to cultivate high-value crops, and stabilizes income overall.

Our findings confirm that overall crop diversity positively affects both environmental and economic outcomes in regions with a large proportion of agriculture (Figure 4). In particular, in areas where the agricultural land ratio is 75% or more, higher crop diversity improves water quality, increases habitat and biodiversity, and stabilizes or boosts farm income. In areas where agricultural land use is minimal (25% or less), however, the effect of crop diversification remains less pronounced.

While Figure 4 primarily captures the broader relationship between overall landscape-level crop diversity and agroecosystem outcomes, it also indirectly highlights the potential role of specialty crops in future diversification efforts. As specialty crops account for a small share of total agricultural land (Figure 1), their immediate impact may appear limited. However, in regions where monoculture dominates, introducing specialty crops could be a key strategy for enhancing landscape diversity and mitigating environmental pressures. The heterogeneity patterns observed in Figure 4 thus offer useful guidance for identifying where specialty crop promotion may be most impactful, particularly in counties with high agricultural intensity and low existing diversity.

## Concluding Remarks

In this article, we discussed and visualized the potential contribution and effects of specialty crops on crop diversity and the positive benefits of crop diversity on various agroecosystem services. We further highlight the importance of constructing a diversified and sustainable agricultural ecosystem.

Our findings suggest that crop diversity may have a greater impact in areas with a stronger agricultural presence than in regions with less agricultural land, indicating a need for region-specific policies and support. Moreover, we found that diversification can benefit not only the environment in terms of water quality, bird diversity, and habitat quality but also farm incomes in regions with a high proportion of agricultural land. This result could provide a partial answer to agricultural producers hesitating to adopt new specialty crops or expand the existing ones due to possible economic loss.

While this article provides a macro-level overview of the contribution of specialty crop diversity, more detailed region- and crop-specific analyses that consider factors such as weather, socioeconomic conditions, and regional differences are needed. Future research could, for example, incorporate advanced econometric models to identify which specialty crops and production practices contribute most to farmers' incomes and agroecosystem services. These research efforts will support policymakers and producers in making well-informed decisions.

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