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Policies for Reintegrating Crop and Livestock Systems: A Comparative Analysis

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Abstract: The reintegration of crop and livestock systems within the same land area has the potential to improve soil quality and reduce water and air pollution, while maintaining high yields and reducing risk. In this study, we characterize the degree to which federal policies in three major global food production regions that span a range of socioeconomic contexts, Brazil, New Zealand, and the United States, incentivize or disincentivize the use of integrated crop and livestock practices (ICLS). Our analysis indicates that Brazil and New Zealand have the most favorable policy environment for ICLS, while the United States provides the least favorable environment. The balance of policy incentives and disincentives across our three cases studies mirrors current patterns of ICLS usage. Brazil and New Zealand have both undergone a trend toward mixed crop livestock systems in recent years, while the United States has transitioned rapidly toward continuous crop and livestock production. If transitions to ICLS are desired, particularly in the United States, it will be necessary to change agricultural, trade, environmental, biofuels, and food safety policies that currently buffer farmers from risk, provide too few incentives for pollution reduction, and restrict the presence of animals in crop areas. It will also be necessary to invest more in research and development in all countries to identify the most profitable ICLS technologies in each region.

Keywords: sustainable agriculture; agroecology; United States; New Zealand; Brazil

1. Introduction

Population growth, urbanization, and increasing affluence will continue to accelerate global demand for fish, dairy, meat, and vegetable oil over the next decade, fueling substantial agricultural expansion and intensification [1]. Agriculture already accounts for the largest appropriation of water and land across the globe, and, in many countries, agriculture is the largest source of greenhouse gas (GHG) emissions [2]. Simultaneously, agriculture is the largest single occupation in the world, employing 40% of the global population and contributing substantially to the health and well-being of rural populations [3]. How we meet this growing demand for food will have profound consequences on global social and ecological well-being.

In this study, we consider a set of agricultural technologies called Integrated Crop and Livestock Systems (ICLS), which aim to reintegrate animals, cropping, and pasture systems to achieve high yields with fewer externalities and to provide a suite of additional ecosystem services, such as carbon sequestration and increased wildlife habitat [4,5]. The (re)integration of crop and livestock systems has the potential to tackle multiple environmental problems at the source by closing the loop in nutrient cycles, improving soil structure and water retention, and decreasing biocide requirements, while still providing high levels of food production and income [6–10].

While ICLS were traditionally the norm over much of the Earth's agricultural history, shifts in agricultural research and policy since the industrial revolution have restructured agriculture toward more specialized and segregated approaches, which have influenced the efficiency, equity, externalities, and ecosystem services associated with global agricultural production [11]. While there are myriad local factors that influence agricultural management [12,13], in this study we focus on the role of national policy contexts, which are a universally important, underlying determinant of agricultural behaviors across the world [14–17]. In particular, we ask: To what extent do national policies *incentivize* ICLS production in three globally important agricultural countries: Brazil, New Zealand, and the United States? We then compare the overall policy context in each country to the historical prevalence of ICLS. Despite the clear importance of policy context for agricultural behavior, no such analysis has ever been conducted for ICLS. Within the suite of technologies defined as ICLS we focus on land-based integration—where the land is rotated through both crop and pastures within the same area, due to their greater importance for the sustainable intensification objectives laid out above [18]. There are other ways that crop and livestock systems can be integrated at larger spatial scales, i.e., via the trade of feed and livestock waste, however these tend to have fewer positive impacts on pollution, soil water retention, and synthetic fertilizer and biocide requirements [18]. For example, Peoschl et al. [19] estimated that manure should not be transported more than 95 km to be used as a fertilizer on cropland or else the emissions associated with its transport will outweigh the emissions saved by its reuse.

2. Design and Methods

2.1. Case Study Selection

We focus our study on Brazil, New Zealand, and the United States because together they represent a wide range of policy contexts and agricultural systems, which makes their comparison helpful for understanding the diverse agricultural contexts present within the global food system. The United States offers the highest level of support for agricultural producers (as a percent of total farm receipts) among the three countries studied here, though support has decreased since the late 1990s (Figure 1). Between 2014 and 2023, the United States will spend more than US$191 billion on agricultural assistance programs, including crop insurance, commodity programs, and conservation efforts [20]. Producer support in Brazil increased substantially after 1995, but remains well below the United States, at roughly US$4 billion per year [21]. Brazil supports agriculture primarily through subsidized credit. Since the late 1980s, New Zealand has provided no price or income support to producers.

Integrated systems take many forms in each country, from small-scale highly diversified production systems to more limited diversity, industrial farms. In Brazil, it is not uncommon for small-scale farms to produce a combination of staple crops (particularly rice, beans, and manioc), fruit, and livestock in agroforestry systems [22–24]. In many regions of Brazil, farmers are too poor to purchase fertilizers and rely instead on livestock excrement and the burning of crop residues to supply plants with nutrients. On larger and more capitalized farms, there has been a push to integrate soy and grain cropping into beef cattle operations, which are the largest land use in the country [25]. The major focus of ICLS in these systems is to help improve soil quality and pasture productivity to increase stocking rates [26].

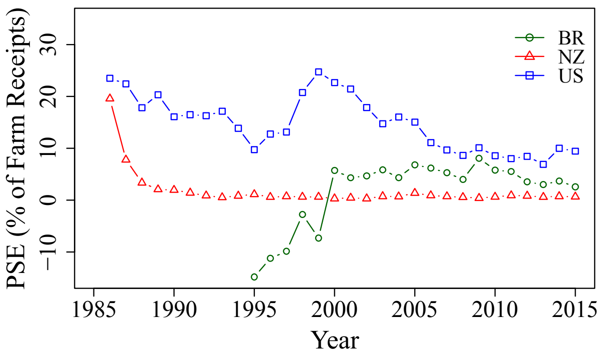

Figure 1. Producer support estimates (PSE) as a percentage of total farm receipts. PSE is measured as the sum of all transfers to agricultural producers (e.g., price supports, input subsidies, etc.) [21]. Note: PSE can be negative when producers receive a lower domestic price than would be found on the world market due to government policies (e.g., an export tax). Data prior to 1995 are not available for Brazil.

In New Zealand, "mixed pasture-arable" farms are common in combination with conventional management (synthetic fertilizers and biocides), but also with organic and biodynamic practices [27–29]. The crops in these systems include wheat, oats, barley, peas, beans, brassicas, turnips, and rapeseed, while the livestock typically include sheep and beef and dairy cattle. In New Zealand, sheep are also frequently integrated into viticulture systems to help reduce herbicide and mowing and improve farm profitability [30,31].

In the United States, there are a growing number of community supported agriculture producers that integrate various types of livestock grazing with cropland [32]. In larger commercial systems the following types of integration can be found: legumes and forages rotated with pastured dairy, cotton rotated with pastured beef, and small livestock grazing in fruit and nut orchards and viticulture systems [33–36]. The integration of pasture and grazing into continuous cropping systems in the United States aims to reduce fertilizer applications for the reduction of GHG emissions and water pollution [7,37]. In the arid high plains and Southwest, a reduction in external water needs is another objective of integration [38]. The use of sheep in orchards and vineyards aims primarily to reduce herbicide use and mowing [39].

While there are few studies examining the economics of ICLS in these three countries, the studies that do exist suggest that various forms of ICLS are economically competitive with analogous forms of continuous crop and livestock production. In Brazil, commercial ICLS farms that integrate grains and beef cattle have similar, and in some cases higher, profits than continuous grain and cattle production [9,10]. While there is little recent research in New Zealand, a widely cited study from 1995 found that mixed arable (grain, pea, and barley) and sheep farms that rely on animal rotations for nutrients produced similar levels of food to conventional farms that relied on synthetic fertilizers, while requiring substantially lower levels of energy inputs [28]. In Texas, integrated beef and cotton systems had a similar economic performance to continuous beef and cotton systems over a 10-year period with a substantially lower water footprint [40]. In Illinois, mixed arable (corn, rye, oat, and turnip) and beef cattle systems had similar profit margins to continuous pasture systems [41].

Finally, we study these countries due to their relevance for global food production. These countries are among the largest producers of ruminant livestock in the world, accounting for a combined 371 million head of cattle, buffalo, and sheep, 29 million tons of milk, and 400 million hectares of pasture (11% of global pasture area) [25,42–44]. Brazil and the United States, in particular, are top ten producers of ruminants, while also the largest producers of corn and soy globally. New Zealand, though it contains less than 3% of the land area of the United States, produces nearly half as many ruminants [44]. New Zealand also produces large volumes of wheat, barley, corn and a variety of high value perennial crops, including wine grapes and apples. Due to the magnitude of crop and animal production in these countries, agriculture accounts for 35% of total greenhouse gas emissions in Brazil, 49% in New Zealand, and 9% in the United States [45–47].

2.2. Data Collection and Methods

To identify policies in our case study regions that incentivize or disincentivize ICLS adoption we employ a *framework analysis* methodology: an established qualitative policy analysis tool [48]. Using this method, a set of relevant current and historical policies are identified using a theoretical framework. They are then indexed and mapped onto the framework to allow for systematic within case and between case interpretation and comparison. In addition to its suitability for comparative case study research designs, framework analysis is useful for applied policy research because it is dynamic and adaptable both during and after analysis based on the analytical process [48].

Following this methodology, we first established a theoretical framework for interpreting how policies are likely to influence farmers' incentives to adopt ICLS (Section 3), and then conducted a thorough, systematic review of agricultural, trade, environmental, food safety, and biofuel policies in each country utilizing the text of major national agricultural and environmental legislation, federal credit and insurance programs, and tariff schedules within each country. In addition, we utilized cross-country international datasets including FAO and OECD agricultural policy summary documents as well as other academic literature that compared agricultural policies across countries. We then mapped these policies onto our theoretical framework for within case interpretation and between case comparative analysis.

To quantify current and historical levels of ICLS adoption, we relied on secondary data from agricultural censuses as far back as 1974. The United States census records how much agricultural area is allocated to a long-term crop and pasture rotation. These data are available every four to five years from 1974 to 2012. The New Zealand census records how much agricultural area is allocated to mixed sheep and grain and mixed beef cattle and grain production. Data are available for 1981 and every five to six years from 1990 to 2012. The Brazilian agricultural census occurs roughly every ten years. Data on how much agricultural area is allocated to mixed crop and livestock systems are available from 1975 to 1996. However, the 2006 agricultural census contains no data on the prevalence of mixed systems. Instead we used data on: (i) what proportion of crop and livestock farms are "diversified" (obtain less than 66% of their income from a single crop or animal; (ii) how many livestock farms use crops to renovate pastures; and (iii) how many crop farms use animal manure as a fertilizer source. It is important to note that the definition of "mixed" systems used in New Zealand and Brazil captures all farms that contain both livestock (in a grazing system) and crops, but does not specify the type of integration occurring.

2.3. Analysis

After mapping and interpreting the policies in each case study region using the framework analysis method [48], we then examined how variations in national policies relate to variations in aggregate levels of ICLS in each country over time. To provide additional context for our systematic review, we also supplement this analysis with data from 130 semi-structured interviews with farmers, Cooperative Extension, and agricultural industry professionals in key production regions within each country from 2014–2015. The interviewees were identified using a snowball sampling approach beginning with contacts given to us by local extension organizations. Institutional Review Board approval was obtained from Harvard University (IRB14-0585) prior to conducting the interviews, and an interview guide was utilized across regions. Our interview guide was pre-tested and tailored for each country in consultation with in-country experts, extension agents and other agricultural industry professionals to ensure the questions were regionally and culturally appropriate. Our interviews asked farmers and other key informants to describe how the national policy context influenced incentives to use ICLS versus continuous crop or pasture management. The interview guide also contained follow up questions to probe their perceptions of specific policies identified by the framework analysis as being important, allowing us to revisit and adapt our prior interpretation and mapping of these policies. Interviews were transcribed and assessed for key themes about regulatory incentives and constraints. Since farmers also frequently discussed non-policy factors that influence their use of ICLS (cultural preferences, social networks, infrastructure, land availability, and climate), we include a discussion of these confounding factors. While the interviews were not the key focus of this analysis, they provided a helpful context to supplement the main policy review methodology.

3. Theoretical Framework

3.1. Policies that Incentivize ICLS

Agricultural policies: The provision of a subsidy or tax break for farms using ICLS will increase incentives to adopt these systems [49]. The establishment of low-interest federal loans to finance investments or costs related to integration will also incentivize ICLS. In developing regions such as Brazil where credit is scarce, enhanced access to public loans can have a particularly strong impact on agricultural behavior by enabling farmers to utilize production systems with higher operating and investment costs [50].

Environmental policies: Policies that create taxes or fines for carbon, nitrogen, or phosphorus emissions or soil erosion force farmers to internalize the costs of pollution and land degradation to society, incentivizing more environmentally responsible production [51]. Since ICLS tend to promote soil conservation and reduce the carbon and nutrient emissions associated with agricultural production [6,8], the introduction of taxes or fines on greenhouse gas and nitrate pollution should encourage their adoption vis-à-vis both continuous cropping and animal confinement systems. Conversely, any public policy that pays farmers for the environmental services provided by their farm will have a similar impact on ICLS adoption, albeit by shifting the burden of payment to taxpayers rather than farmers.

Knowledge support systems: Federally supported research and extension directly focused on ICLS can help incentivize the adoption of these management systems [49]. Long term agronomic and animal health research can help improve the yields of these systems [49], while economic research can help identify which systems are most efficient. Demonstration farms and extension programs can help spread information about the potential benefits of ICLS and technical details about how to operate such systems [52].

3.2. Policies that Disincentivize ICLS

Agricultural policies: Any policy that reduces the profitability of ICLS relative to continuous crop and livestock systems will serve as a disincentive for ICLS. For example, subsidies for tractors could act as a disincentive for forms of ICLS that take advantage of draught power as an alternative to machinery. In places where continuous systems are the norm, payments based on current or recent historical production may serve as disincentive for ICLS by discouraging farmers from transitioning into new land uses [53].

As a more diversified form of production vis-à-vis continuous crop monocultures or single animal systems, ICLS can be an important mechanism for reducing farmers' risk [54,55]. Therefore, policies that provide subsidized insurance on margin or production losses will also reduce incentives for ICLS and encourage specialization.

Food safety: Policies that create restrictions and fines regarding the presence of animals or animal excrement in cropland areas will disincentivize many forms of ICLS. The impact of these food safety restrictions will depend on the types of crops they apply to (typically non-food crops and crops that are processed or intended for home consumption are excluded) and the minimum exclusion time between animal grazing or manure application and planting.

3.3. Policies with Mixed Impacts

Agricultural policies: Policies that substantially increase prices paid to producers for individual crops, such as price supports, direct payments, subsidies, or consumption mandates, can incentivize the use of continuous cropping systems. However, these same supports may disincentivize the use of animal confinement systems in favor of ICLS or continuous pasture by creating higher feed prices. If production subsidies (and price supports) are focused on a very limited set of crops, they may discourage forms of ICLS that include other types of crops (Table 1).

Trade policies: Higher import restrictions or tariffs on imported feeds and fertilizers should incentivize ICLS adoption over confinement animal systems by making homegrown feed and fertilizer (e.g., crop residues and animal manure) more competitive. Nevertheless, protective tariffs may also incentivize continuous cropping of the protected crop by artificially increasing its price.

Table 1. Policies that influence farmers' incentives to use integrated crop and livestock systems (ICLS).

Policy Category	Policy Instrument	Mechanism of Impact
Policies that incentivize ICLS		
Agriculture	Tax breaks, subsidies, or subsidized credit for ICLS	Decrease costs of ICLS
	Incentives for soil conservation, GHG reduction, or water pollution reduction	
Environment	Carbon, water pollution or GHG fines or taxes	Increase costs of continuous production systems
Knowledge support	Research funding and extension for ICLS	Increase yields and efficiency of ICLS
Policies that disincentivize ICLS		
Agriculture	Subsidized insurance against production or margin loss	Reduce risk of continuous systems
	Payments based on production	Discourage any production change
Environment	Exemptions from pollution regulations for confinement systems	Decrease costs of animal confinement systems
Food safety	Restrictions on applying manure or animal grazing in cropland areas	Increase costs or ban ICLS
Policies with mixed impacts		
Agriculture	Price or income support for individual crops	Increase revenues of continuous crop systems; increase costs of confinement livestock systems if target crops are used for feed
Trade	Import restrictions or taxes on fertilizers, livestock feed, or feed crops	Feed and fertilizer import tariffs increase costs of continuous production systems; Crop import tariffs can increase revenues associated with continuous crop systems
Biofuels	Biofuel mandates that inflate the prices of individual crops for specific markets	Increase revenues of biofuel crop systems; increase or decrease costs of confinement livestock systems depending on byproducts available
Environment	Policies restricting conversion of native ecosystems to agricultural land	Encourage intensification of continuous pasture systems, which could lead to the adoption of ICLS or confined livestock systems

Biofuel policies: Mandates for biofuels in energy consumption portfolios can inflate the prices of grains and oilseeds [56], which tend to be key sources of feed in non-pastured livestock systems. High costs of feed could encourage livestock farmers to diversify into an integrated system. On the other hand, biofuel production generates byproducts, such as distillers grains that can be used as cheap, local sources of livestock feed [57]. The presence of these cheap feeds could discourage ICLS, which rely on grasses and forage crops as the primary source of animal nutrition.

Environmental policies: Policies that influence agricultural land availability by restricting the conversion of native ecosystems can also influence choices in agricultural management by altering the relationship between the price of land and other inputs. As land becomes more expensive, incentives to intensify production by increasing non-land inputs will increase [58]. In response to increasing land prices, farmers may choose ICLS as a way to intensify continuous pasture systems, or avoid land inputs altogether by adopting confined livestock systems.

3.4. Caveats

The list of policies examined here is not exhaustive and includes only policies that are likely to have a direct impact on ICLS usage. Other policies that could ultimately influence ICLS outcomes include macroeconomic policies, minimum wage laws, and fuel taxes, among others. The presence of many incentivizing policies in a country does not guarantee the use of ICLS. However, it does increase its likelihood. The impact of each policy and actual use of ICLS will depend on the presence of other constraints (e.g., biophysical conditions, supply chain infrastructure, labor markets, and financial capital), as well as farmers' personal preferences and perceptions of the costs and benefits of ICLS (discussed in Sections 6.2 and 6.3) [52]. While we have disaggregated policies into the categories of incentivizing or disincentivizing, the lack of a disincentivizing policy can also be seen as an explanatory factor for ICLS, given the comparative nature of this analysis.

4. Policy Context

4.1. Brazil

Agricultural policies: Agricultural policy in Brazil over the last sixty years has focused on modernization and increasing exports [59,60]. During the agricultural reforms of the 1980s, subsidies and price controls for sugarcane, wheat, coffee, and milk were reduced. Support for all crops and animal products is now provided primarily through the National Rural Credit System (Sistema Nacional de Crédito Rural (SNCR)), which provides agricultural loans at lower than market interest rates, and the Federal Government Purchase program (Aquisições do Governo Federal (AGF)), which enables the government to purchase crops at a minimum target rate if sellers cannot find a better market [59]. Currently farmers receive a majority of support through subsidized credit programs. In 2015/2016, the government allocated US$70 billion (using an exchange rate of 0.379 Brazilian Reais per US Dollar from January 2015 (www.x-rates.com)) in loans for commercial agriculture and US$11 billion for family agriculture [61,62].

Credit is applicable for a wide range of management practices, however there are special credit lines for ICLS, agroforestry systems, and agro-ecological production as part of Brazil's Low Carbon Agriculture (ABC) Plan [62]. To date, uptake of ABC loans has been limited to about two-thirds of the available funds and has been concentrated in the Center West and Southeast regions [26]. Lack of land title, onerous documentation requirements, and the existence of credit lines with lower interest rates are among the causes for low ABC credit uptake [63].

Farmers are required to purchase insurance for investment loans, but there is only limited federal insurance for production or income losses for large farmers (US$253 million), compared to federal support for commercial agriculture (US$71 billion). Insurance is available through private sources, but often prohibitively expensive [64,65]. Small farmers are required to purchase coverage through the Insurance for Family Farmers (SEAF) program when they access subsidized loans through the Program for Strengthening Family Agriculture. However, currently this program reaches less than 1% of farmers [25,66]. In 2011, all public and private mechanisms for mitigating risks in agriculture were accessed by 1.55 million farmers, covering 18% of the agricultural area in Brazil [65].

In 2013, Brazil enacted the National Integrated Crop-Livestock-Forestry Policy (Law 12805), aimed at reclaiming degraded pastures, increasing agricultural productivity and quality, improving farmer income, and mitigating deforestation pressures and GHG emissions [67]. This law defines integrated systems as a priority for preferential loans and other infrastructure benefits, e.g., energy, irrigation, and storage.

Trade policies: Brazil has very high tariffs on fertilizer imports (>20%) and livestock feed (>30%) [68]. High import tariffs for fertilizer are particularly relevant for ICLS uptake, since domestic deposits of phosphorus and potassium are not sufficient to meet national demand. In 2015, national production accounted for only 30% of total domestic fertilizer consumption [69].

Environmental policies: Brazil has several important water, air, hazardous waste pollution policies, including the National Environmental Policy Law (Law No. 6938—1981) and Environmental Crimes Law (Law No. 9605—1998), which establishes the polluter pays principal and fines for pollution; the Water Resources Law (Law No. 9433—1997), which establishes water as a public good to be protected; the Agricultural Policy Law (Law No. 8171—1991), which defines environmental protection as an objective of the country's agricultural agenda; and the Agrotoxics Law (Law No. 7802—1989), which regulates the production, trading, and application of fertilizers and pesticides. Nevertheless, these environmental laws are rarely enforced, making them largely ineffective [70]. The Forest Code (discussed below), requires farms to maintain riparian buffers to help protect water quality.

Brazil has several state PES programs, collectively referred to as ICMS Ecológico. These programs re-distribute taxes to municipalities, which in turn pay local landowners for conservation activities [71]. However, PES payments tend to be oriented toward the creation of conservation areas, not multifunctional forms of agriculture.

In 2009, Brazil enacted a National Climate Policy (Law No. 12187) with commitments to reduce GHG emissions across all sectors by 36%–39% in 2020, in comparison with the business as usual scenario. To meet this commitment, the Brazilian government aims to reduce deforestation by 80% versus 1995–2005 levels and reduce emissions from existing farms by promoting the adoption of low carbon technologies. [72,73]. Another policy aimed at reducing GHGs in Brazil is the Forest Code (Law 12651), which mandates that agricultural properties set aside a specific proportion of their property for conservation (80% for forest areas and 35% for savanna areas in the Legal Amazon and 20% in other regions). The Forest Code has been around since 1965, but enforcement was greatly improved in the 2000s through several mechanisms including fines, increased field visits, credit exclusion, and the confiscation of illegally acquired goods or assets [74]. Revisions to the Forest Code in 2012 established a Rural Environmental Registry, which requires farmers to register their property with state environmental agencies and develop a plan to come into compliance with conservation requirements [75]. Under Forest Code regulations, Brazilian farmers must restore a cumulative 21 million hectares of Legal Reserve areas [76]. As a complement to these public policies, in the late 2000s many soy and cattle companies developed initiatives to avoid sourcing products associated with deforestation, including the Soy Moratorium agreement [77] and the "G4" zero-deforestation agreement [78], which also acted to reduce land available for agricultural expansion.

Biofuels policies: The Brazilian government has invested heavily in biofuels production since the 1970s. The ProAlcool program aimed to decrease reliance on fossil fuels by creating an automobile vehicle fleet that would run on ethanol rather than gasoline, and later, both gasoline and ethanol. In 2013, 47% of the Brazilian fleet had flex-fuel engines, versus 41% running on gasoline [79]. This program was supported by substantial subsidies to both the automobile and sugar sectors [80]. Sugarcane ethanol is also supported by a mandatory blend requirement in gasoline (ethanol must comprise 27% of the total fuel). The Brazilian Biodiesel Law of 2005 sets a mandatory blend requirement for biodiesel in diesel fuel (2% of the total fuel) [81]. Brazil's Agroenergy Plan of 2006–2011 provides further support for biofuels production by allocating more resources toward the generation of knowledge and technologies that can improve the competitiveness of biofuel production [82]. The production of sugarcane ethanol produces by-products that can be used as cattle feed; however, 88% of the bagasse produced from ethanol production is used for energy cogeneration in ethanol production plants [83].

Food safety policies: Food safety laws in Brazil are geared toward processing facilities and complying with the sanitary and phytosanitary regulations of importing countries [84]. Brazil does not have restrictions on the use of animal grazing or manure in food crop areas.

Knowledge support systems: Agricultural research is spearheaded by the Brazilian Agricultural Research Corporation (Embrapa), which is financed mainly by the federal government [85]. Additionally, Embrapa coordinates the National Agricultural Research System that includes all state research organizations. Since the 1980s, Embrapa has been doing research on ICLS in beef cattle systems as a mechanism to restore degraded pastures. In the early 1990s, six existing Embrapa state research units in the North region were transformed in Agroforestry Research Centers. This restructuring process strengthened research and development on agroforestry and integrated crop, livestock, and forestry systems in deforested areas [86]. Federal research on ICLS increased substantially during the 2000s to examine the potential benefits of a larger variety of integrated systems [87]. One outcome of this process was the establishment of a research unit in the state of Mato Grosso focused primarily on ICLS (*Embrapa Agrossilvopastoral*) [88]. *Embrapa Agrossilvopastoral* functions as a hub for research on low carbon agriculture technologies and system integration, housing researchers from several other Embrapa centers and enabling communication between these experts.

4.2. New Zealand

Agricultural policies: Farmers in New Zealand receive no support through minimum prices or direct payments [89]—all agricultural subsidies were removed in 1984. As a result, New Zealand has the lowest support for agriculture of any OECD country (producer supports are estimated at 0.7% of gross farm receipts) [90]. Crop insurance in New Zealand is voluntary and unsubsidized. In 2007, 1500 operations, comprising 5% of farmers and 10,000 hectares were covered. Livestock insurance covered only 2% of farmers [91]. The Ministry of Primary Industries Adverse Events Recovery Framework provides limited coverage in the case of large-scale adverse events, including weather-related disasters. In the case of such an event, a Special Recovery Mechanism (SRM) kicks in, which may partially recover costs to on-farm infrastructure. However, this fund only covers privately insurable property, not losses in income or production. Furthermore, in the case of a large-scale biosecurity event, farmers would not receive compensation for infected plants and animals [92].

Trade policies: New Zealand has no tariff on fertilizer imports and a 5% tariff on imported animal feeds [93]. However, five separate biosecurity acts and standards regulate the import of animal feeds, including the Import Health Standard, Animal Products Act (1999), Agricultural Compounds and Veterinary Medicines Act (2011), Biosecurity (Ruminant Protein) Regulations (1999), and the Biosecurity Act (1993). These acts make it relatively expensive to import feed or feed components [94]. Fonterra, the largest dairy company in the world, and virtual monopoly in New Zealand, encouraged farmers to keep palm kernel rations (an imported feed source) at 3 kg per animal per day in 2015 [95]. Nevertheless, fertilizer and feed imports (particularly for dairy) are high in New Zealand and have continued to increase since policy reforms in the 1980s [89].

Environmental policies: New Zealand's major environmental regulation is the Resource Management Act (RMA) of 1991 (Public law No. 69), which regulates that the use of land must be consistent with "national environmental standards, regional rules, or district rules". The RMA and other environmental regulations are administered by Regional Councils, who are tasked with issuing permits for resource consents (activities that may influence environmental quality, including agriculture). The 2014 National Policy Statement for Freshwater Management reinforces the responsibilities of regional councils for dealing with these issues, clarifying their responsibility under the RMA for decision-making and management planning. The policy statement emphasizes responsible use of water resources with respect to climate change, prohibits the over-allocation of water, and charges Regional Councils with mitigating adverse effects. The most significant aspect of the regulation was to establish a minimal acceptable condition for freshwater across a variety of contaminant parameters. Regional Councils with particularly acute water quality issues (i.e., Taupo, Waikato, and Canterbury) have either already or are currently implementing regional policies related to nitrogen management through caps and trading programs. In 2007, New Zealand implemented an Emissions Trading Scheme, which thus far does not include agriculture, but does require reporting of agricultural greenhouse gas emissions.

Knowledge Support Systems: Government sponsored research is run through Crown Research Institutes (CRIs), which are quasi-government/industry funded. Research activities are broadly separated by major industries (i.e., AgResearch for pasture-based agriculture; Plant and Food for horticulture and viticulture) and specific production systems have their own industry organizations (i.e., DairyNZ, Beef and Lamb, DeerNZ, etc.). In general, the specialization of many CRIs toward individual commodities can be viewed as a disincentive for integration, however, there is some focus within CRIs to conduct research on ICLS. For example, Plant and Food work on integrating sheep into vineyards, while AgResearch works on crop, forage, pasture, and sheep/beef and dairy integration. In addition to directly funding research, each institute heavily influences, through its industry ties, technology transfer, and research implementation. The New Zealand Agriculture Greenhouse Gas Research Center pursues a research agenda of reducing greenhouse gas emissions across sectors by partnering with the industry group DairyNZ and the CRI AgResearch to conduct analysis of integrated systems [96]. The Sustainable Farming Fund invests up to $8 million per year in research and extension programs led directly by farmers to fill gaps in industry-funded research by opening a grass-roots award mechanism focused on sustainability to farmers. Several of the funded projects in SFF's portfolio are explicitly directed toward integration [97].

Food safety policies: New Zealand has four laws that apply to Food Safety, The Animal Products Act (1999), the Food Act (1981), the Agricultural Compounds and Veterinary Medicines Act (1997), and the Wine Act 2003, but these acts contain no specific provisions regarding the presence or use of animals or manure on cropland area [98].

Biofuels policies: In New Zealand, the government passed a Biofuel Bill in 2008, which was set to require a percentage of biofuels be added to gasoline and diesel; however, this was repealed later under the Energy Biofuel Obligation Repeal Act of 2008 [99]. Instead, New Zealand has provided grant funding for biofuel research and exempts bioethanol from excise tax (50.5 cents per liter) [100].

4.3. United States

Agricultural policies: United States farmers receive very high levels of federal support. However, the type of support they receive has shifted greatly in the last fifty years. Historically, agricultural policy was focused on both incentivizing and stabilizing production of grains, oilseeds, sugar, cotton, and dairy to meet domestic consumption needs and protect farmers [101]. The Farm Bill of 1933 established minimum price floors and price subsidies [102]. To make sure farmers did not over-produce, it established acreage controls and payments for set asides. Since 1938, subsidized insurance has been available for a wide variety of crops. Starting in 1965 the Farm Bill reduced price supports for farmers and provided income supports based on production. Throughout the 1990s, these fixed income supports were de-coupled from current production levels and instead based on historical production [101].

Direct payments and subsidies were completely repealed in the 2014 Farm Bill, though price supports still exist for a limited number of products such as dairy. The Farm Bill instead shifted to the provision of subsidized insurance coverage for both yield and price related losses. In areas where there are no available crop insurance options, the Noninsured Crop Assistance Program provides coverage for losses due to weather. Uptake of insurance programs is fairly widespread—28% of the crop, pasture, and rangelands were insured as of 2012 [103].

The Farm Bill has included measures to promote soil conservation since 1933 and in 1985 the Farm Bill created the Conservation Reserve Program (CRP), which pays farmers to remove land from production for at least 10 years [102]. Since 1990, the Farm Bill has included additional environmental considerations, including the Environmental Benefits Index (EBI), which helps prioritize land for conservation across multiple environmental attributes, and the Environmental Quality Incentives Program (EQIP), which provides financial and technical assistance for investments in environmental protection. Notably, EQIP provides financial assistance to confined livestock producers (concentrated animal feeding operations) to install lagoons and other storage facilities to control animal waste. The 2014 Farm Bill's Conservation Stewardship Program (CSP) and EQIP both provide payments to farmers for several ICLS related behaviors such as: not burning crop residue (residue can instead be used as feed), intensive rotational grazing (pasture can be rotated with crops), transition to organic cropping systems (manure from livestock substitutes for chemical fertilizers), and nutrient and feed management. The Conservation Technical Assistance (CTA) program also provides information on how to reduce pollution into waterways by installing riparian buffers.

Trade policies: There are zero import tariffs for fertilizers [104]. There are also zero or very low import tariffs for livestock feeds depending on the country of origin and precise type of feed [104]. The United States currently imports more than 50% of its nitrogen and potassium needs [105]. Though the United States is major exporter of corn and soybeans it is also dependent on grain and oilseed imports to meet demand for livestock feeds, which exceeds domestic production [106].

Environmental policies: The United States has a comprehensive suite of environmental regulations that are relevant for agricultural practices. The Clean Water Act aims to mitigate the pollution of water through the approval of discharge permits (33 U.S.C. §1251; 1972), many of which are required of Confined Animal Feeding Operations (CAFOs) if they propose to discharge to water. Additionally, the Safe Drinking Water Act protects underground sources of drinking water by regulating how farms handle both liquid waste and wastewater and requires regular sampling of drinking water to identify microbial contamination (42 U.S.C. §300f; 1974). The Clean Air Act quality standards requires State Implementation Plans that identify sources of air pollution and determine what reductions are required for each specific state context (42 U.S.C. §7401; 1970). Regulations on limiting emissions of nitrogen oxides and volatile organic compounds are particularly relevant for CAFOs, which are known to emit odors. The Resource Conservation and Recovery Act requires that pesticides, manure, and crop residues are disposed of or managed in accordance with pertinent laws at the state or local levels (42 U.S.C. §6901; 1976). However, farmers are often provided with exemptions and violations are rarely enforced [107].

Knowledge support systems: In the United States, agricultural research is mainly supported through the Farm Bill and the National Institute of Food and Agriculture (NIFA). NIFA funds several programs that are salient to ICLS, including programs on sustainable agriculture, organic agriculture, soil health, manure and nutrient management, and risk management education [108]. NIFA also supports the Land-Grant University System and several of these universities have research looking specifically at ICLS, including: Washington State, Iowa State, North Dakota State, Ohio State, North Carolina State, and Texas Tech. Recently, NIFA has also developed several grant programs that support research on ICLS [109,110]. More recently, the USDA Agricultural Research Service established a Long-Term Agroecological Research Network in the Northern Great Plains that includes research on the social and ecological dimensions of ICLS in dryland farming systems [111]. Nevertheless, allocations to ICLS comprise only 15% of the $135 million in agricultural research funding that is provided by the 2014 Farm Bill per year [109,110].

Food safety policies: The Food Safety Modernization Act of 2011 provides standards for the safe production and harvesting of food crops and has the potential to impact certain forms of ICLS adoption through rules related to the presence of animals and use of animal excrement on cropland that produces food for human consumption. The Final Rule on Produce Safety outlines restrictions on the use of raw manure in areas used to produce fruits and vegetables [112]. The rule establishes: (i) numerical limits on *E. coli* (zero detectable) and other potentially dangerous microbes; (ii) a 120-day and 90-day waiting periods between the application of raw manure and the planting of crops in contact with the soil and planting crops not in contact with the soil (affirming existing national organic standards), respectively; and (iii) farmers must monitor wildlife intrusion and prevent contamination with animal feces. While these regulations provide potential benefits for public health, they could discourage the integration of animals into non-organic food crops and tree fruit systems. However, these food safety rules do not influence the integration of animals into cropland used for the production of grains, beans, and foods for home consumption, since these areas are exempt from the policy.

Biofuel policies: Though a long-standing (30-year) ethanol tax credit expired in 2012, a number of other policies promote the production of ethanol in the United States. In 2005, the Energy Policy Act (PL 109-58) established the Renewable Fuel Standard (RFS), which requires that certain percentages of transportation, heating, and jet fuels are replaced by biofuels. Initially, the RFS required that four billion gallons of biofuel be used in 2006, which would rise to 7.5 billion by 2012. In 2007, The Energy Independence and Security Act (PL 110-140) expanded this mandate to require the use of nine billion gallons of biofuels in 2008 ultimately expanding to 36 billion gallons in 2022, of which no more than 15 billion gallons could be corn-based ethanol. While the policy intends to transform the biofuel mandate to more advanced cellulosic biofuels in the future, currently the majority of the mandate is met by corn ethanol [113,114]. Roughly 37% of United States corn produced in 2014–2015 was used for ethanol [115].

5. ICLS Prevalence

5.1. Brazil

Mixed crop and livestock systems were in decline from 1975 to 1985 and then increased substantially, accounting for 16% of livestock area and 11% of crop area in 1996 (Figure 2) [116]. Since the farm classification system changed in 2006, it is unclear whether mixed or integrated crop and livestock levels increased further after 1996. In 1996, 20% of crop farms used animal manure or urine for fertilizer, while, in 2006, 12% of crop farms relied on this source of fertilizer. As of 2006, 7% of livestock farms used a crop rotation as a way to improve pasture quality, accounting for 23% of the national agricultural area (37 million hectares) [25]. While the data indicate that nearly 50% of farms were diversified in more than one product, they are not highly diversified; on average 68% of all farms in Brazil produced only two agricultural items [25] (calculated in the same way as Dimitri et al., 2005 [101]). While various elements of ICLS are common among Brazilian farms, fewer farms meet Embrapa's technical definition of ICLS. Embrapa researchers estimate that as of 2016, integrated crop livestock production occurs on 9.5 million hectares (4%) of the 224 million hectares in agriculture [117].

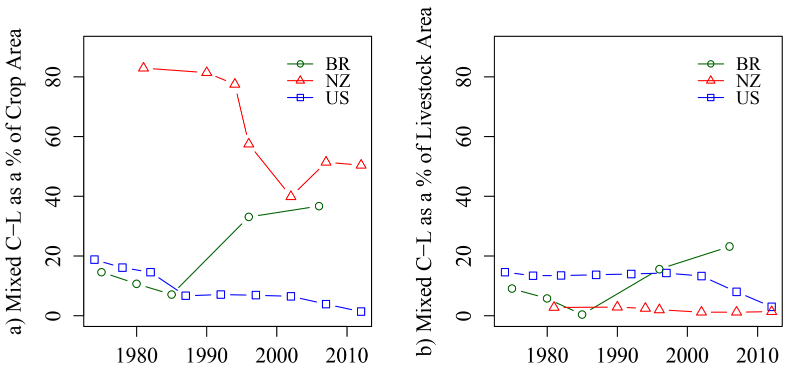

Figure 2. Mixed crop and livestock production as a proportion of: crop area (**a**); and livestock area (**b**) in each country (1974–2012). Mixed systems are more common in Brazil and New Zealand and substantially less common as a proportion of livestock area in all countries, particularly in New Zealand. Notes: Livestock area includes both planted pastures and natural grass and rangelands. The mixed crop and livestock data from New Zealand only include mixed sheep and grain and mixed beef cattle and grain.

5.2. New Zealand

Mixed grain-sheep and grain-beef production declined between 1980 and 2002, but then increased from 2002 to 2012. As of 2012, 50% of grain cropping area (127,000 hectares) and 44% of grain farms (471 farms) were in mixed use with beef or sheep grazing [118]. Additionally, 65% of the nitrogen fertilizer applied on farms was derived from livestock manure as of 2010 [119]. Livestock areas are less integrated, with less than 2% of beef and sheep grazing area and farms in mixed use with grain cropping. Dairy production is also highly specialized, relying heavily on off-pasture areas to supplement cattle [120], however the New Zealand Agricultural Census does not record area in mixed use with grain cropping on dairy farms. The census also does not provide data on mixed sheep and viticulture production, which is thought to be quite common by local experts.

5.3. United States

United States farms were substantially more diversified and integrated in the 1970s than they are today. In 1974, 52% of the area and 19% of the farms utilized a crop-grazing rotation. By 2012, only 7% of the farms and <2% of the agricultural area were undergoing this rotation [121]. In 1970, US farmers produced an average of three items on their property, but now produce only one [101], though the major crop regions of the United States typically include a two crop rotation [7]. Remote sensing studies confirm that the trend toward the homogenization is deepening, with mixed use areas being rapidly converted to continuous annual crops [122]. While crop livestock integration *within* farms has decreased substantially, integration *between* farms is still occurring. As of 2010, 34% of the nitrogen fertilizers used by United States farmers came from livestock urine or manure, rather than synthetic sources [119].

6. Relationship between Policy Context and ICLS Adoption

6.1. Aggregate Trends in Policy Incentives and ICLS Prevalence

Brazil and New Zealand provide the most incentives for ICLS, while the United States provides several disincentives (Table 2). In Brazil, subsidized credit for ICLS, high import taxes on fertilizers and livestock feed, and research funding and extension for ICLS make mixed crop and livestock production attractive. The absence of insurance mechanisms for income losses or food safety restrictions on animal integration in cropland further incentivizes ICLS. All of these factors explain why ICLS utilization is generally higher in Brazil than the United States. In terms of timing, however, the deregulation of several important agricultural crops and the economic instability of the 1990s (an issue not covered here in detail) may explain the notable uptick in mixed systems after 1985, since beef cattle became more competitive with other forms of agriculture and served as an asset to reduce risk from currency fluctuations [123]. More recently, restrictions on deforestation have played an important role in encouraging the intensification of continuous pasture systems [124,125], either through the adoption of pasture improvement techniques, such as ICLS, or confinement systems.

In New Zealand, the major incentivizing policies for ICLS are water pollution regulations, biosecurity requirements on feed imports, and targeted research funding. The absence of price and income supports and a lack of subsidized crop or livestock insurance also play an important role in incentivizing ICLS. After subsidies for agriculture were removed in 1984, beef and sheep production systems underwent rapid intensification to become competitive in global markets [89]. This was enabled by a large increase in feed imports [89]. As farmers abandoned grain and grazing rotations in favor of supplementation with external feed, the prevalence of mixed systems declined. Meanwhile, specialized horticulture production increased rapidly [126]. The area in mixed systems and cropping both reached a low in 2002, when lamb prices were substantially higher than grain prices [127]. In more recent years, the trade commission and private industry cracked down on the types of feeds that could be imported and used in production and farmers faced increasingly variable global prices, creating new external incentives to adopt ICLS and reduce risk in the absence of price protections or insurance.

As such, rates of crop integration among beef and sheep farms have grown. Nevertheless the dairy industry, which relies heavily on feed concentrates, remains highly specialized, despite increased interest in finding ways to re-utilize homegrown pastures and crops [120].

The United States provides incentives for ICLS in the way of fines for water pollution, incentives for soil conservation, and a growing investment in ICLS research. However, historical price and income supports, and continued subsidized insurance programs have reinforced incentives for specialized agricultural production [54], contributing to the constant decline of mixed systems in the United States since the 1970. Furthermore, restrictions on food safety make it impossible to practice certain forms of ICLS, making a reversal of this trend difficult, even though many producer supports were removed in the 2014 Farm Bill. The impacts of United States biofuels mandates on ICLS are unclear. By contributing to high global corn prices, United States biofuels policies have increased acreage devoted continuous corn production [122,128,129] with ripple effects on soy area in Brazil and other regions [56,130]. Higher corn prices are projected to reduce confined livestock production in the United States [131], which might in turn benefit the pasture based ICLS in Brazil and New Zealand [132]. However, the availability of cheap distillers grains has mitigated some of the negative impacts on confinement systems [131].

Table 2. Integrated crop and livestock system (ICLS) relevant policies in Brazil, New Zealand, and the United States.

Brazil	New Zealand	United States
Policies that incentivize ICLS		
• Subsidized credit for ICLS • High import taxes on fertilizers and livestock feed • Research funding and extension for ICLS	• Water pollution fines • Import restrictions on livestock feed • Research funding for ICLS	• Water pollution fines • Incentives for soil conservation and water pollution reduction • Research funding for ICLS
Policies that disincentivize ICLS		
		• Subsidized insurance against production and margin loss • Restrictions on manure and animal grazing in cropland areas
Policies with mixed impacts		
• Price supports for commodity crops • Biofuel mandates for sugarcane and soy • Restrictions on the conversion of forest to cropland		• Biofuel mandates for corn

The balance of policy incentivizes and disincentives across our three cases studies mirrors current patterns of ICLS usage. Brazil and New Zealand have both undergone a trend toward greater use of mixed systems in recent decades, while the United States has undergone a rapid transition toward continuous crop and confined livestock systems. In both Brazil and New Zealand, mixed systems are substantially more common as a proportion of total cropland area, since both countries have very large amounts of land in continuous pasture, grassland, and rangeland. In the United States integration is equally low as a proportion of crop and pasture/rangeland area.

6.2. Farmers' Perceptions of ICLS Incentives

Our interviews elicited more details on how the above policy contexts influenced farmers' incentives to adopt ICLS. While we asked respondents to discuss policies that both encourage and inhibit ICLS adoption, interviewees tended to focus more on barriers, i.e., policies that were either directly inhibiting ICLS or were not functioning as well as they could in incentivizing ICLS.

In Brazil, farmers mentioned that they would be more likely to use ICLS if they were able to access government subsidized credit for these systems. They were aware that credit programs existed, but felt that excessive bureaucracy was limiting their ability to obtain this credit. They also expressed the need for insurance on their investments, should ICLS fail to generate anticipated benefits. A failure of the public extension system was another frequently cited problem. While numerous research projects on ICLS currently exist in Brazil, the ability of agricultural experts to transfer this knowledge to farmers was perceived as very weak. Despite problems with credit access, many cattle ranchers expressed a desire to adopt ICLS as a way to intensify and add value to their continuous pasture systems in light of increasing restrictions on forest conservation for agriculture. Since the mid-2000s, efforts to improve enforcement of the Forest Code and the implementation of zero-deforestation commitments by soy and cattle traders have acted to reduce land availability for agricultural expansion in the Amazon and encourage intensification on cattle farms [124,125].

In New Zealand, farmers discussed the policy reforms of the 1980s. They stated that the removal of subsidies provided incentives for them to improve their efficiency by intensifying and to reduce their risk by diversifying. Diversification into both sheep or beef and cropping allowed them respond quickly to changes in the relative prices of crops versus lamb and beef and keep feed costs low. These changes are confirmed by other studies [89,133]. Ironically, the more recent introduction of nitrogen regulations in New Zealand was seen as a disincentive for ICLS in some regions. Farmers mentioned that increasing regulations on nitrogen runoff could lead them to build confinement systems (housing cattle on concrete pads and bringing in imported feed) during the winter in order to apply nitrogen as needed, rather than grazing the animals on cropland areas. However, they also stated that the increasing regulations would force them to come up with answers to the environmental challenges and become better farmers.

In the United States fear over food safety regulations was commonly mentioned by the farmers we interviewed as a barrier to integration. Farmers who stopped using animal manure because of food safety issues complained about the low quality of the compost used to replace manure. However, the paperwork involved with using manure was seen as too high and not worth the effort. The food safety regulations were perceived as particularly challenging for leafy greens producers, which have been subject to high levels of scrutiny over *E. coli* outbreaks [134].

Farmers in all three countries mentioned a desire to see payments for environmental services (PES) implemented to reward them for the social benefits provided by ICLS. However, none of the countries analyzed here have a national system of PES.

6.3. Confounding Factors

Levels of ICLS utilization across countries might also be due to confounding issues not studied here. For example, ICLS require a diverse union of supply chain infrastructure and knowledge systems that enable access to markets for multiple products, as well as integration of information regarding best practices among different functional types of agriculture [52]. In Brazil, many agricultural regions have limited agribusiness infrastructure, extension services, and a lack of land tenure [135,136], which constrain farmers' ability to adopt ICLS [52]. One Brazilian farmer stated, "*Integrated systems can help with many things here, but we don't have the financial conditions to make this investment*".

ICLS also require land that has adequate soil, topography, temperature, and rainfall patterns to support both crops and livestock. Steep slopes, common to many regions of New Zealand, are prohibitive for mechanized agriculture and lend themselves to extensive ruminant livestock production. In arid regions, water availability could be a major barrier to integration if it is not sufficient for crop or pasture systems. For example, in the Central Valley of California many dairy cattle have zero access to grazing and instead consume feeds, forages, silages, and concentrates brought in from other regions [137]. As one interviewee told us, "*You are never going to see high levels of integration in dairy in the Central Valley. There just isn't enough water.*" On the other hand, integrating cattle into continuous cropping regions has been shown to have major benefits for profitability and sustainability in light of decreasing water availability in the high plains region of the United States [38].

Finally, differences in the lifestyle and cultural benefits associated with ICLS versus specialized crop or cattle production may be particularly important since these systems are qualitatively different from most traditional forms of agriculture in the level of complexity and diversity they involve [52]. These cultural preferences create inertia for land use change. As one Brazilian rancher said, "*Sometimes a rancher just wants to be a rancher. However, the government thinks now ranchers should contribute to development. Why can't we just be happy?*"

6.4. Policy Implications

Our analysis suggests numerous policy changes that could increase incentives for ICLS in the study regions. These include: (i) tying insurance programs in Brazil and the United States to the adoption of agricultural practices that reduce climate risk; (ii) strengthening environmental policies (and enforcement) that punish nutrient runoff and reward nutrient recycling in all countries; (iii) reducing food safety restrictions on the integration of animals and manure in cropland in United States; and (iv) strengthening research and development for ICLS in all countries. In all countries, ICLS uptake could benefit from a system of payments for the environmental services provided by sustainable agricultural practices, as occurs in Europe [138]. Other policies that encourage ICLS: taxes on feed and fertilizer imports, biofuels mandates, and land conservation requirements, may also make conditions more favorable for specialized systems. These policies should only be used in a mix with the above-mentioned climate and environmental policies to avoid "free-riding" from specialized producers.

In considering all of these policy changes, the net benefits conferred through ICLS will need to be weighed against the net benefits of existing and potential future policies (e.g., food safety and energy independence versus environmental benefits). While the changes in policy we have suggested represent fairly incremental changes to the existing policy structure, they may still be politically infeasible, depending on the prevailing political context in each region.

7. Conclusions

Reintegrating crop and livestock systems has the potential to address several ecological and social objectives for agriculture: producing high yields, reducing pollution and external fertilizer and biocide dependence, reducing climate vulnerability, promoting more diverse on-farm habitat, and reducing risk to market fluctuations. However, little is known about the current prevalence of integrated systems or the policy conditions that would support their uptake among farmers in major global production regions.

In this study, we characterize the degree to which federal policies in three major production regions, Brazil, New Zealand, and the United States, incentivize ICLS adoption. Our analysis shows that the policy contexts in Brazil and New Zealand, where ICLS is the most common, provide the most favorable policy environment for ICLS, while the United States offers the least favorable policy environment. To promote transitions to ICLS, particularly in the United States, it will be necessary to change and better coordinate agricultural, trade, environmental, biofuels, and food safety policies that currently buffer farmers from risk, provide too few incentives for pollution reduction, and restrict the presence of animals in crop areas due to food safety concerns. It will also be necessary to invest more in research and development in all countries to identify the most profitable ICLS technologies in each region. To better understand how other regions and policies may incentive or disincentive the adoption of ICLS, we suggest that additional policy-oriented research be conducted across a greater diversity of countries.

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