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Assessment of Current Practices of Organic Farmers Regarding Biological Soil Amendments of Animal Origin in a Multi-regional U.S. Study

ABSTRACT

Certified organic producers use biological soil amendments of animal origin (BSAAOs) to improve soil fertility and quality. Criteria for prevention of microbial contamination of crops have been based on the time interval between the application and crop harvesting. The objective of this study was to assess current practices related to the use of BSAAOs and food safety risks in organic agriculture, with a focus on produce commodities covered under the Produce Safety Rule. A total of 666 producers completed the survey (571 online and 95 hardcopy); 89.2% (594/666) of the respondents produced fresh produce. Eighty-two percent of the producers were certified organic and represent relatively small- to medium-size farms. BSAAOs were applied by 46.8% of producers growing produce that is typically consumed fresh. Fifty-eight percent of the farmers reported the use of raw manure. This survey showed that multiple factors related to on-farm manure management practices, which may directly affect survival and persistence of pathogens in manure-amended soils, vary by region and by state in the U.S. Thus, mitigation practices to decrease the risk of potential microbial contamination to fresh produce resulting from application of untreated manure must take into account multiple factors across different regions. This survey provides a framework for risk mitigation strategies to reduce microbial contamination of fresh produce in systems using BSAAOs, mainly untreated manure, in organic agriculture.

INTRODUCTION

The organic food industry has an enormous socio-economic impact, with annual sales in excess of $7.6 billion in 2016 *(40)*. Produce, fruits, tree nuts and berries accounted for 40.3% of the organic food sales in 2016 *(40)*, and consumer demand for organic products continues to grow, with sales increasing every year *(12, 17)*. The growing demand for organic products is accompanied by the perceived guarantee of quality, safety, and sustainably produced food products *(12, 17)*. Certified organic producers often use animal-based soil amendments to improve soil fertility and quality *(32, 33)*. Application of biological soil amendments (BSAs), including partially or

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incompletely composted, uncomposted and untreated animal manure (hereafter called "raw manure"), benefits several soil properties, including nutrients, water retention, permeability, water infiltration, drainage, aeration, and structure *(32, 33)*. Although many crop-based agricultural operations utilize biological soil amendments of animal origin (BSAAOs), these amendments are particularly important to certified organic farmers, because USDA's National Organic Program (NOP) prohibits the use of synthetic chemical fertilizers *(39)*. Because manure from livestock species may carry foodborne pathogens, including *E. coli* O157:H7, *Salmonella* spp., *Campylobacter* spp., *Listeria* and *Cryptosporidium parvum (19)*, the risk of pathogen spread via fresh produce and fruits typically consumed raw (without cooking) is increased when untreated manure is applied to crop fields *(29)*. Moreover, fresh produce presents a unique food safety challenge because of the absence of a kill step between harvest and consumption *(47)*. Raw manure application as well as compost processing and application practices, must be adequate to reduce the risk of potential crop contamination *(6, 21, 28)*.

The nutrient and microbiological characteristics of animal manure-based soil amendments (e.g., untreated soil amendments and compost) depend on factors such as animal source (e.g., cattle, swine, small ruminants and poultry), animal diet, bedding material (e.g., amount, and type), and type of manure (e.g., solid, slurry, or liquid) *(16)*. The survival of foodborne pathogens in the soil, animal manure, and compost varies depending on the livestock species, pathogen, manure (e.g., type and management), compost composition (e.g., humidity, organic matter, dry matter, and heat development during composting), carbon source (e.g., wood, pine needles, and straw), soil characteristics (e.g., texture, moisture, and nutrient content), and environmental conditions (e.g., season, ambient temperature, rainfall, humidity, and sunlight) *(8–11, 16, 19, 26, 36)*. Controlled and managed composting processes have been shown to suitably reduce the populations of foodborne pathogens to acceptable levels *(4, 25)*. Despite standards established for compost parameters such as temperature, organic matter, and oxygen, factors such as those just mentioned affect the quality and microbial characteristics of the final product *(8, 9)*. Additionally, cultural factors in farming communities may present barriers to changing from traditional uses of raw manure to adaptation of composting standards.

The USDA-National Organic Program (NOP) regulations for use of raw, untreated manure on crops are based on criteria related to the time interval and crop-soil contact between the application of animal-based soil amendments and time of crop harvest, to prevent microbial contamination. However, this NOP rule has little scientific data supporting the efficacy of these wait times in minimizing the risk of microbial contamination in organic farming systems and in determining how agricultural practices may affect microbial contamination and survival. FDA is conducting a risk assessment and, in collaboration with the U.S. Department of Agriculture and other stakeholders, is undertaking critical research to provide scientific support for appropriate time interval(s) between application of raw manure and harvest of fresh produce *(46)*.

The Food Safety Modernization Act (FSMA), Produce Safety Rule, Subpart F, defines a BSAAO as "untreated" if it has not been processed to adequately reduce microorganisms of public health significance *(45)*. The rule requires that untreated BSAAOs must be handled, conveyed, and stored in such a manner that it does not contact covered produce during application, so as to minimize the potential for contact with covered produce after application. Additionally, in the preamble of the rule, the FDA does not object to the National Organic Program (NOP) standard, which requires that untreated animal manure be applied at least 120 days or 90 days prior to crop harvest, depending on whether the edible portions come into direct or indirect contact with the manure-amended soil *(43, 45)*. However, the FDA is reserving a final decision on the wait time between application of raw manure and produce harvest until more data are collected and a risk assessment is completed *(45)*. This highlights the general lack of scientific data supporting any wait time regulations or agricultural practices (NOP or FSMA) to protect the food safety of fresh produce.

Numerous studies have reported on the high variability of factors (e.g., animal source, type of manure, soil composition, environmental conditions, pathogen, and livestock) that can affect pathogen survival in animal-based soil amendments and soil. These factors might be directly related to the type of livestock production and agricultural practices, which vary between regions and states. Additional sound science-based data are needed regarding the food safety risks and the current practices related to the use of soil amendments in organic farming. The objective of this study was to assess current practices used on organic farms relative to the use of biological soil amendments of animal origin, including rotational grazing and composting, in order to identify potential food safety risks related to pathogen contamination and potential threats to the public health, as well as any innovative practices used to reduce such risks. Specifically, this study aimed to characterize the use of soil amendments, including rotational grazing of livestock and poultry, in organic and sustainable agriculture, with a focus on produce (e.g., vegetables, nuts and fruits) commodities covered under the Produce Safety Rule.

MATERIALS AND METHODS

Recommended methods to increase survey response rates were followed *(7)*, including newsletter announcements, industry meetings, conferences, social media, blogs and personal communications. The survey instrument and the methods developed were approved for use with human

subjects by the Institutional Review Board, University of California, Davis. The survey instrument was developed by project personnel and were reviewed for content validity and readability by an advisory board of researchers, extension specialists, and producer-grower organization representatives (7 total). The questionnaire was then revised and pretested with selected farmers in California (3 total). The survey contained an introductory cover letter explaining the goals of the survey, funding sources, authors and contacts. In the absence of a unique sample frame, i.e., a list of the organic farmers to be drawn from, a non-probability sampling was conducted in order to obtain a maximum number of participants. The survey was publicized via e-mail invitations, listserves, newsletters, and conferences and was posted in social media from nationwide organic organizations (The Organic Center, Organic Trade Organization, and National Sustainable Agriculture Coalition {NSAC}), regional organic associations (California Certified Organic Farmers {CCOF}, Midwest Organic and Sustainable Education Services {MOSES}, Northeast Organic Farming Association-Vermont {NOFA-VT}, Maine Organic Farmers and Gardners Association {MOFGA}, Ohio Ecological Food and Farm Association {OEFFA}, and Pennsylvania Association for Sustainable Agriculture {PASA}, and conferences (2016 Minnesota Organic Farming Conference, 2016 Future Harvest, 2016 US Composting Council, 2016 EcoFarm, and 2016 California Small Farm Conference). The survey was published online (www.surveymonkey.com) and web links were sent to farmers/growers, who were asked to complete a Web survey. Additionally, a mail survey was sent to a farmer list (553 total) from a non-profit organization in the Midwest, in order to target growers, including Plain farming communities, who did not have access to the Internet. A reminder postcard was sent to all mail survey recipients ten days following the initial delivery, and reminder emails were sent twice within 2 weeks to the listserves and the email list of The Organic Center (7,000 certified organic producers across the U.S.). The survey included 65 questions total, grouped in 7 sections, to collect demographic information and information on use of BSAAOs, use of raw and untreated manure, use of compost, crop and field practices, good agricultural practices, and testing and verification of BSAAOs. Survey questions required selection of the most appropriate answer or more than one answer, as well as answering of open-ended questions. Hardcopy survey responses were received by an independent appointee and entered into the online survey. Integrity and completeness were validated and entered into a database by a second appointee. STATA version 14 (StataCorp. LP, College Station, Texas, U.S.) was used to calculate frequencies and percentages of the sample population. Pearson X2 analysis with Bonferroni adjustment (SAS, 9.4., SAS Institute Inc., Cary, NC, USA) was used to compare the proportion of respondents using raw manure, compost and treatment in each region. A significance level of 0.05 was used for all comparisons.

RESULTS

A total of 666 producers completed the survey (571 online and 95 hardcopy). The estimated response rate for the online survey was 8.2% (571/7,000, based on The Organic Center listserves) and the rate for the hardcopy survey was 17.2 % (95/553). The producers not growing produce (10.8%, 72/666) were excluded from further survey descriptive analysis. Eighty-two percent (81.8%, 486/594) of the participant producers were USDA-NOP certified organic, 1.7% (10/594) were in USDA transition certification, and 2.2% (13/594) were conventional. Regarding the crop types, 89.2% (594/666) of the participants produced fresh produce.

Demographics

The demographic findings stratified by region are shown in *Table 1*. Of the 75% (447/594) of the producers surveyed who responded to a question about state location, 42.7% (191/447) were located in the West, 27.5% (123/447) in the Midwest, 19.2% (86/447) in the Northeast, and 10.5% (47/447) in the Southern regions of the U.S. Of those who responded to a question about farm size (76%, 450/594), 30.4% (137/450) farmed on 10 acres or less, 35.6% (160/450) on 10 to 80 acres, and 34.0% (153/450) on 81 or more acres. Sixty-four percent (379/594) of producer participants responded to a question about annual produce sales in the previous three years *(Table 1)*. Of those, 35.1% (133/379) had a revenue of less than $25,000; 49.3% (187/379) between $25,000 and $500,000, and 15.6% (59/379) greater than $500,000 *(Table 1)*. Of the 454 respondents who answered the question about their position on the farm, 86.6% (393/454) were owners or co-owners *(Table 1)*. Of 438 respondents who answered the question about number of years farming, 36.5% (160/438) had been farming for less than 11 years, 49.8% (218/438) for 11 to 40 years, and 13.7% (60/438) for more than 40 years *(Table 1)*. The number of year-round employees per farm was 20 or less for 94.4% (403/427) of the participants. The farms were located in rural areas for 85.4% (381/446) of the participants *(Table 1)*.

Manure types and characteristics

Description of the type of biological soil amendments use by region are shown in *Table 2*. Among the producers who indicated using at least one of the following types of raw manure, compost or heat treated animal products as BSAs, 90.4% (359/397), 91.9% (397/432), and 47.4% (199/420) used products that contained animal manure (aged or stacked manure, slurries, poultry litter, animal bedding) respectively; 64.2% (255/397), 68.5% (296/432) and 46.0% (193/420) used products that contained a blend of green waste (e.g., yard trimmings, food waste) and animal manure, respectively *(Table 2)*. Fish emulsion was the animal product used as heat treated BSAs by the majority of the participants (82.9%, 348/420) *(Table 2)*.

TABLE 1. Demographics of a needs assessment survey to assess current practices of organic farmers on use of biological soil amendments in a multi-regional U.S. study

		Regional distribution of farms* % (count)					
		West	Midwest	Northeast	South	No answer	Total
		32.2 (191)	20.7 (123)	14.5 (86)	7.9 (47)	24.7 (147)	594
Farm size	10 acres or less	34.0 (64)	14.6 (18)	38.8 (33)	44.7 (21)	14.3 (1)	30.4 (137)
	10 to 80 acres	34.0 (64)	39.8 (49)	36.5 (31)	27.7 (13)	42.9 (3)	35.6 (160)
	81 acres or greater	31.9 (60)	45.5 (56)	24.7 (21)	27.7 (13)	42.9 (3)	34.0 (153)
	*Response Rate***	*98.4 (188)*	*100.0 (123)*	*98.8 (85)*	*100.0 (47)*	*4.8 (7)*	*75.8 (450)*
Annual produce sales	$25,000 or less	28.7 (50)	46.2 (36)	32.1 (25)	51.2 (21)	12.5 (1)	35.1 (133)
	$25,000 to $500,000	45.4 (79)	51.3 (40)	56.4 (44)	46.3 (19)	62.5 (5)	49.3 (187)
	More than $500,000	25.9 (45)	2.6 (2)	11.5 (9)	2.4 (1)	25.0 (2)	15.6 (59)
	*Response rate***	*91.1 (174)*	*63.4 (78)*	*90.7 (78)*	*87.2 (41)*	*5.4 (8)*	*63.8 (379)*
Years of farming	10 years or less	33.2 (62)	40.3 (48)	32.9 (27)	50.0 (22)	16.7 (1)	36.5 (160)
	11 to 40 years	54.0 (101)	42.0 (50)	52.4 (43)	45.5 (20)	66.7 (4)	49.8 (218)
	41 years or more	12.8 (24)	17.6 (21)	14.6 (12)	4.5 (2)	16.7 (1)	13.7 (60)
	*Response rate***	*97.9 (187)*	*96.7 (119)*	*95.3 (82)*	*93.6 (44)*	*4.1 (6)*	*73.7 (438)*
Year-round employees	20 or less	88.3 (166)	99.0 (102)	100.0 (84)	100.0 (46)	83.3 (5)	94.4 (403)
	More than 20	11.7 (22)	1.0 (1)	0	0	16.7 (1)	5.6 (24)
	*Response rate***	*98.4 (188)*	*83.7 (103)*	*97.7 (84)*	*97.9 (46)*	*4.1 (6)*	*71.9 (427)*
Farm location	Rural	85.3 (162)	92.2 (107)	82.4 (70)	72.3 (34)	100.0 (8)	85.4 (381)
	Suburban/Peri-Urban	14.7 (28)	7.7 (9)	17.7 (15)	27.6 (13)	0	14.5 (65)
	*Response Rate***	*99.5 (190)*	*94.3 (116)*	*98.8 (85)*	*100.0 (47)*	*5.4 (8)*	*75.1 (446)*

*Percentages for region cumulate in a row. Other percentages cumulate down a column based on number of responses from each region.
**Percentages for response rate are based on total of 594 participants.

Description of the practices associated with the use of BSAAOs are shown in *Tables 3 to 5*. Among producers who gave at least one answer, BSAs containing animal manure (including raw, untreated and treated manure, and compost) were applied by 60.0% (260/433) of producers growing produce that is typically consumed fresh (uncooked or unprocessed), 50.1% (217/433) were applied by producers growing produce typically consumed cooked or processed, and 41.3% (177/433) were applied by producers grew forage crops for livestock or grain crops *(Table 3)*. Producers responded that it was very important or important to use BSA's containing animal manure for soil health (90.9%, 468/515), nutrient management (86.7%, 445/513), soil tilth (85.1%, 421/495), cost (62.8%, 300/478), and animal waste management (45.6%, 214/469). The main animal sources of manure used as BSAs were poultry (69.4%, 340/490), cattle (60.8%, 298/490), horses (40.4%, 198/490), and small ruminants (24.3%, 119/490).

Fifty-eight percent (324/556) of producers reported using raw manure as a BSA *(Table 3)*. The proportion of participants using raw manure as BSAs was significantly different between the West (49.7%, 95/191)) and Midwest (78.9%, 97/123) regions and between the Midwest and Northeast (61.6%, 53/86) regions, but not between the West and South (57.4%, 27/47) regions *(Table 3)*. Among

TABLE 2. Type of biological soil amendments in needs assessment survey to assess current practices of organic farmers on use of biological soil amendments in a multi-regional U.S. study

		Regional distribution of farms* % (count)					
		West	Midwest	Northeast	South	No answer	Total
Type of raw manure***	Animal manure	83.9 (94)	97.1 (100)	93.2 (55)	85.7 (30)	90.9 (80)	90.4 (359)
	Animal products	48.2 (54)	30.1 (31)	37.3 (22)	17.1 (6)	38.6 (34)	37.0 (147)
	Green and animal manure/products	69.6 (78)	56.3 (58)	72.9 (43)	54.3 (19)	64.8 (57)	64.2 (255)
	*Response rate***	*58.6 (112)*	*83.7 (103)*	*68.6 (59)*	*74.5 (35)*	*59.9 (88)*	*66.8 (397)*
Type of compost***	Animal manure	90.4 (132)	96.3 (79)	89.7 (61)	88.5 (23)	92.7 (102)	91.9 (397)
	Animal products	48.6 (71)	35.4 (29)	41.2 (28)	30.8 (8)	47.3 (52)	43.5 (188)
	Green and animal manure/products	69.9 (102)	63.4 (52)	76.5 (52)	53.8 (14)	69.1 (76)	68.5 (296)
	*Response rate***	*76.4 (146)*	*66.7 (82)*	*79.1 (68)*	*55.3 (26)*	*74.8 (110)*	*72.7 (432)*
Type of treated animal products***	Animal manure	42.6 (63)	45.7 (32)	47.7 (31)	41.2 (14)	57.3 (59)	47.4 (199)
	Bone meal	44.6 (66)	40.0 (28)	52.3 (34)	55.9 (19)	53.4 (55)	48.1 (202)
	Blood meal	41.2 (61)	40.0 (28)	50.8 (33)	55.9 (19)	51.5 (53)	46.2 (194)
	Feather meal	52.0 (77)	35.7 (25)	41.5 (27)	61.8 (21)	48.5 (50)	47.6 (200)
	Fish emulsion	81.1 (120)	82.9 (58)	87.7 (57)	85.3 (29)	81.6 (84)	82.9 (348)
	Seaweed emulsion	66.9 (99)	58.6 (41)	73.8 (48)	58.8 (20)	74.8 (77)	67.9 (285)
	Green and animal manure/products	43.2 (64)	38.6 (27)	47.7 (31)	50.0 (17)	52.4 (54)	46.0 (193)
	*Response rate***	*77.5 (148)*	*56.9 (70)*	*75.6 (65)*	*72.3 (34)*	*70.1 (103)*	*70.7 (420)*

*Percentages cumulate down a column based on number of responses from each region.
**Percentages for response rate are based on total of 594 participants.
***Participants could select more than one option; therefore, percentages for each region may exceed 100%.

raw manure users who responded, the main sources of raw manure were poultry (48.6%, 154/317), cattle (44.2%, 140/317), horses (35.7%, 113/317), and small ruminants (21.8%,69/317). Forty-eight percent (246/594) used compost as BSA *(Table 3)*. The proportion of participants using compost as BSA was significantly different between the West (57.1%, 109/191) and Midwest (32.5%, 40/123) regions and between the Midwest and the Northeast (52.3%, 45/86) regions, but not significantly different between the Southern (36.2%,17/47) region and any other region *(Table 3)*.

Manure treatments

Of those who used raw manure, 73.7% (224/304) did not treat the raw manure on their property prior to application onto fields, and 28.2% (87/308) did treat the raw manure *(Table 4)*. The proportion of participants treating raw manure was significantly different among the West (41.9% (39/93) and the Midwest (12.5% (12/96) and South 14.8% (4/27) regions, and between the Midwest and Northeast (31.4%, 16/51). Composting (51.2%, 44/ 86) was the most common type of treatment reported by the respondents. Raw manure piles were the most common storage type used prior to field application (79.6% 246/309), followed by storage pit and slurry (15.9%, 49/309) *(Table 4)*. Over 77.3% (238/308) of those who used raw manure indicated that the manure was produced on site, 47.1% (145/308) locally but not commercially, and 26.9% (83/308) on commercial locations *(Table 4)*. Regarding the time between storage and

TABLE 3. Use of Biological Soil Amendments (BSAs) of animal origin by crop and region in a needs assessment survey to assess current practices of organic farmers on use of biological soil amendments in a multi-regional U.S. study

		Regional distribution of farms* % (count)					
		West	Midwest	Northeast	South	No answer	Total
Use of BSAs containing animal manure by crop type***	Fresh produce	53.9 (82)	56.1 (55)	75.8 (50)	82.4 (28)	54.2 (45)	60.0 (260)
	Produce cooked or processed	47.4 (72)	43.9 (43)	66.7 (44)	61.8 (21)	44.6 (37)	50.1 (217)
	Forage crops for livestock & grains	21.7 (33)	80.6 (79)	37.9 (25)	26.4 (9)	39.7 (33)	41.3 (179)
	Orchards	56.6 (86)	26.5 (26)	31.8 (21)	38.2 (13)	37.3 (31)	40.9 (177)
	*Response rate***	*79.6 (152)*	*79.7 (98)*	*76.7 (66)*	*72.3 (34)*	*56.5 (83)*	*72.9 (433)*
Use of raw manure §	Yes	49.7 (95)^{ac}	78.9 (97)^{b}	61.6 (53)^{c}	57.4 (27)^{c}	47.7 (52)	58.3 (324)
	No	50.3 (96)	21.1 (26)	38.4 (33)	42.6 (20)	52.3 (57)	41.7 (232)
	*Response rate***	*100.0 (191)*	*100.0 (123)*	*100.0 (86)*	*100.0 (47)*	*74.1 (109)*	*93.6 (556)*
Use of compost §	Yes	57.1 (109)^{ac}	32.5 (40)^{b}	52.3 (45)^{a}	36.2 (17)^{abc}	53.0 (35)	48.0 (246)
	No	42.9 (82)	67.5 (83)	47.7 (41)	63.8 (30)	47.0 (31)	52.0 (267)
	*Response rate***	*100.0 (191)*	*100.0 (123)*	*100.0 (86)*	*100.0 (47)*	*44.9 (66)*	*86.4 (513)*

*Percentages cumulate down a column based on number of responses from each region.
**Percentages for response rate are based on total of 594 participants.
***Participants could select more than one option; therefore, percentages for each region may exceed 100%.
§Different superscript letters indicate a significant difference ($P < 0.05$) of growers using raw manure or compost among states.

application of raw or untreated manure, 38.3% (100/261) responded that the duration was 120 days or less, and 37.2% (97/261) reported a duration greater than 120 days *(Table 4)*. Responses to an open-ended question indicated that there was a wide range of application frequency and treatment methods of raw manure; the majority of the respondents (68.5% , 174/254) reported application once or twice a year *(Table 4)*. Spring and fall were the seasons most often reported as the time of manure applications.

Compost

Forty-eight percent (48%, 246/513) of respondents reported that they used compost *(Table 5)*. Among those, 44.3% (109/246) were located in the West, 18.3% (45/246) in the Northeast, 16.3% (40/246) in the Midwest, and 6.9% (17/246) in the South *(Table 5)*. The main sources of compost were commercial (74.6%, 154/232), on-site (50.0%, 116/232), and local (23.7%, 55/232) *(Table 5)*. The main types of on-site composting processes were windrow turned composting (64.8%, 129/199), and aerated static pile on-site (22.1%, 44/199) *(Table 5)*. Of those who used compost, 52.9% (127/240) incorporated it into the soil, 49.5% (119/240) applied it to surface, 39.2% (94/240) spread it, and 28.3% (68/240) side-dressed it. Over 77.5% (165/213) of those who used compost indicated that application was conducted one to two times per year. Spring and fall were the seasons in which compost was most frequently applied *(Table 5)*. The most common type of compost storage reported was outdoors, with or without any covering *(Table 5)*.

Crop type

Table 6 shows the treatment status of the BSAs used by type of crop grown. Raw manure was mostly used in forage crops for livestock (62.4%, 123/246). It was also used by 28.0% (69/246) of respondents growing produce crops that typically are cooked or processed, and by only 24.7% (67/271) of respondents growing fresh produce, i.e., typically commodities consumed raw without cooking or heat processing *(Table 6)*. Compost was the major soil

TABLE 4. Practices regarding use of raw manure in in a needs assessment survey to assess current practices of organic farmers on use of biological soil amendments in a multi-regional U.S. study

Raw manure users (count)		Regional distribution of farms* % (count)					
		West	Midwest	Northeast	South	No answer	Total
		95	97	53	27	52	324
Source of raw/untreated manure***	Commercial	32.6 (30)	24.0 (23)	19.2 (10)	22.2 (6)	34.1 (14)	26.9 (83)
	Local non-commercial	46.7 (43)	43.8 (42)	42.3 (22)	63.0 (17)	51.2 (21)	47.1 (145)
	Produced on site	76.1 (70)	88.5 (85)	73.1 (38)	70.4 (19)	63.4 (26)	77.3 (238)
	*Response rate***	*96.8 (92)*	*99.0 (96)*	*98.1 (52)*	*100.0 (27)*	*78.8 (41)*	*95.1 (308)*
Treatment of raw/untreated manure §	Yes	41.9 (39)[a]	12.5 (12)[b]	31.4 (16)[a,c]	14.8 (4)[b,c]	39.0 (16)	28.2 (87)
	No	58.1 (54)	87.5 (84)	68.6 (35)	85.2 (23)	61.0 (25)	71.8 (221)
	*Response rate***	*97.9 (93)*	*99.0 (96)*	*96.2 (51)*	*100.0 (27)*	*78.8 (41)*	*95.1 (308)*
Method used for treatment of raw manure	Compost	61.5 (24)	33.3 (4)	56.3 (9)	25.0 (1)	40.0 (6)	51.2 (44)
	Other****	38.5 (15)	66.7 (8)	43.8 (7)	75.0 (3)	60.0 (9)	48.8 (42)
	*Response rates*****	*100.0 (39)*	*100.0 (12)*	*100.0 (16)*	*100.0 (4)*	*93.8 (15)*	*98.9 (86)*
Storage of raw/untreated manure***	Manure pile	76.3 (71)	77.3 (75)	88.2 (45)	74.1 (20)	85.4 (35)	79.6 (246)
	Manure storage pit and slurry	11.8 (11)	22.7 (22)	9.8 (5)	14.8 (4)	17.1 (7)	15.9 (49)
	Containers or indoor	10.8 (10)	21.6 (21)	15.7 (8)	11.1 (3)	0	13.6 (42)
	No storage	14.0 (13)	4.1 (4)	5.9 (3)	11.1 (3)	9.8 (4)	8.7 (27)
	*Response rate***	*97.9 (93)*	*100.0 (97)*	*96.2 (51)*	*100.0 (27)*	*78.8 (41)*	*95.4 (309)*
Duration of raw manure storage prior to application	No storage	17.6 (15)	10.8 (8)	9.1 (4)	8.0 (2)	9.1 (3)	12.3 (32)
	Less than 90 days	29.4 (25)	33.8 (25)	36.4 (16)	40.0 (10)	33.3 (11)	33.3 (87)
	90 to 120 days	7.1 (6)	1.4 (1)	9.1 (4)	4.0 (1)	3.0 (1)	5.0 (13)
	More than 120 days	38.8 (33)	36.5 (27)	36.4 (16)	32.0 (8)	39.4 (13)	37.2 (97)
	Period overlap	7.1 (6)	17.6 (13)	9.1 (4)	16.0 (4)	15.2 (5)	12.3 (32)
	*Response rate***	*89.5 (85)*	*76.3 (74)*	*83.0 (44)*	*92.6 (25)*	*63.5 (33)*	*80.6 (261)*
Frequency of manure application	3+ times a year	8.9 (7)	5.1 (4)	2.3 (1)	4.3 (1)	0	5.1 (13)
	1–2 times a year	72.2 (57)	61.5 (48)	76.7 (33)	73.9 (17)	61.3 (19)	68.5 (174)
	Every 2+ years	19 (15)	33.3 (26)	21.0 (9)	21.7 (5)	38.8 (12)	26.4 (67)
	*Response rate***	*83.2 (79)*	*80.4 (78)*	*81.1 (43)*	*85.2 (23)*	*59.6 (31)*	*78.4 (254)*

(Continued on next page)

amendment used in growing fresh produce (56.8%, 154/271) and produce that is cooked or processed (51.6%, 127/246) *(Table 6)*. The application method of animal manure varied among the participants and included field spreading (53.2%, 166/312), soil incorporation (43.6%, 136/312), surface application (43.6%, 136/312), and dressing (9.9%, 31/312).

TABLE 4. Practices regarding use of raw manure in in a needs assessment survey to assess current practices of organic farmers on use of biological soil amendments in a multi-regional U.S. study (cont.)

Raw manure users (count)		Regional distribution of farms* % (count)					
		West	Midwest	Northeast	South	No answer	Total
		95	97	53	27	52	324
Season of application of raw/untreated manure***	Winter	41.8 (38)	43.3 (42)	7.8 (4)	33.3 (9)	42.5 (17)	35.9 (110)
	Spring	50.5 (46)	64.9 (63)	62.7 (32)	63.0 (17)	40.0 (16)	56.9 (174)
	Summer	16.5 (15)	33.0 (32)	35.3 (18)	11.1 (3)	30.0 (12)	26.1 (80)
	Fall	56.0 (51)	80.4 (78)	78.4 (40)	70.4 (19)	65.0 (26)	69.9 (214)
	*Response rate***	*95.8 (91)*	*100.0 (97)*	*96.2 (51)*	*100.0 (27)*	*76.9 (40)*	*94.4 (306)*

*Percentages cumulate down a column based on number of responses from each region.
**Percentages for response rate are based on total of 324 raw manure users.
***Participants could select more than one option; therefore, percentages for each region may exceed 100%.
****These respondents self-identified their raw manure treatment method as aging *(37)* or biodynamics *(5)*.
*****Percentages for response rate are based on total of 87 producers who treat their manure.
§Different superscript letters indicate a significant difference ($P < 0.05$) of growers using raw manure among state participants.

Eighty percent of respondents (140/174) said they asked for verifications about processing time, temperature and compost turning or BSA treatment methods for purchased compost, and 80.8% (193/239) said the compost manufacturing facilities were validated by an independent accredited third party.

Wait-time interval between manure application and crop harvest

Over 90.7% (223/246) of respondents who used raw manure indicated using a 90-120-day waiting period between application and harvest, and few (5.7%, 14/246) waited less than 90 days, as recommended by the National Organic Program *(43)* for crops that directly contact the soil and crops that do not. In addition, 4.1% (10/246) indicated they follow the Leafy Greens Marketing Agreement guidelines (a one-year wait period) *(24)*. Seventy percent (70.2%, 158/225) of the producers indicated that the waiting period between application and crop harvest differed by crop type.

Rotational grazing

Rotational grazing (e.g., farms integrating crop-livestock production and animals, crops occupy the same field at different times) *(18)* was used by 26.0% (129/496) as part of crop management by the surveyed individuals (84%, 496/594) who answered this question. The rotational grazing was used in the following crop types: cover crops (73.9%, 68/92), nut and fruit orchards (47.8%, 44/92) and fresh produce (37.0%, 34/92). The animal species used in grazing were cattle (52.1%, 63/121), poultry (49.6%, 60/121), small ruminants (39.87%, 48/121), equids (19.0% , 23/121) and swine (15.7%, 19/121). Ninety-one percent (91.1%, 82/90) of responders said they followed time intervals between grazing and harvest of produce.

Standard operating procedures and protocols

Sixty-five percent (64.50% , 200/310) of producers reported having written standard operating procedures (SOPs) and/or good agricultural practices (GAPs) protocols to reduce the risk of transmission of foodborne pathogens (e.g., *Salmonella*, *E. coli* O157:H7) from raw manure to fresh produce. Regarding preventive practices to avoid contamination of fresh produce from raw manure, 70.4% (216/307) had specific equipment and tools for handling raw manure, 83.0% (190/229) provided worker training on raw manure and potential food safety risks, and 33% (196/ 594) controlled traffic around raw manure storage areas. Several reasons were given for traffic control, such as prevention of agricultural water contamination (79.6%, 156/196), prevention of produce fields contamination (78.6%, 154/196), and prevention of re-contamination of composted or treated soil amendments (40.8%, 80/196).

Forty percent (39.6%, 95/240) of producers reported protecting soil amendments during treatment from animal intrusions, and 29.1% (173/594) used at least one method (e.g., covers, berms, hedgerows, wind breaks or fence) to minimize run-offs from stored raw manure.

In case of accidental raw manure contamination of produce fields, corrective actions were reported having been taken by only 25.9% (154/594) of respondents. Corrective actions

TABLE 5. Practices regarding use of compost in in a needs assessment survey to assess current practices of organic farmers on use of biological soil amendments in a multi-regional U.S. study

Compost use		Regional distribution of farms* % (count)					
		West	Midwest	Northeast	South	No answer	Total
		109	40	45	17	35	246
Source of compost***	Commercial	83.8 (88)	71.1 (27)	56.8 (25)	75.0 (12)	72.4 (21)	74.6 (173)
	Local non-commercial	22.9 (24)	28.9 (11)	25.0 (11)	25.0 (4)	17.2 (5)	23.7 (55)
	Produced on site	50.5 (53)	50.0 (19)	52.3 (23)	37.5 (6)	51.7 (15)	50.0 (116)
	*Response rate***	*96.3 (105)*	*95.0 (38)*	*97.8 (44)*	*94.1 (16)*	*82.9 (29)*	*94.3 (232)*
Composting method	Windrow turned composting	70.0 (63)	58.6 (17)	60.0 (24)	61.5 (8)	63.0 (17)	64.8 (129)
	Aerated static pile	18.9 (17)	27.6 (8)	22.5 (9)	15.4 (2)	29.6 (8)	22.1 (44)
	Static enclosed composting	5.6 (5)	3.4 (1)	12.5 (5)	0	0	5.5 (11)
	Other or not composted on site	5.5 (5)	10.2 (3)	5 (2)	23.1 (3)	7.4 (2)	7.5 (15)
	*Response rates***	*82.6 (90)*	*72.5 (29)*	*88.9 (40)*	*76.5 (13)*	*77.1 (27)*	*80.9 (199)*
Storage of compost***	Outside not covered	64.2 (68)	62.5 (25)	58.1 (25)	43.8 (7)	64.5 (20)	61.4 (145)
	Outside covered	32.1 (34)	12.5 (5)	34.9 (15)	31.3 (5)	22.6 (7)	28.0 (66)
	Inside	0.9 (1)	0	2.3 (1)	0	0	0.8 (2)
	Open or closed container	4.7 (5)	17.5 (7)	18.6 (8)	31.3 (5)	12.9 (4)	12.2 (29)
	No storage	9.4 (10)	7.5 (3)	2.3 (1)	0	9.7 (3)	7.2 (17)
	*Response rate***	*97.2 (106)*	*100.0 (40)*	*95.6 (43)*	*94.1 (16)*	*88.6 (31)*	*95.9 (236)*
Frequency of compost application	3+ times a year	8.7 (9)	15.6 (5)	7.9 (3)	6.7 (1)	8.3 (2)	9.4 (20)
	1–2 times a year	80.8 (84)	78.1 (25)	78.9 (30)	80.0 (12)	58.3 (14)	77.5 (165)
	Every 2–4 years	8.7 (9)	6.3 (2)	13.2 (5)	13.3 (2)	33.3 (8)	12.2 (26)
	Never	1.9 (2)	0	0	0	0	0.9 (2)
	*Response rate***	*95.4 (104)*	*80.0 (32)*	*84.4 (38)*	*88.2 (15)*	*68.6 (24)*	*86.6 (213)*
Season of compost application***	Winter	36.3 (37)	25.6 (10)	9.5 (4)	50.0 (7)	38.5 (10)	30.5 (68)
	Spring	60.8 (62)	56.4 (22)	57.1 (24)	85.7 (12)	57.7 (15)	60.5 (135)
	Summer	21.6 (22)	20.5 (8)	31.0 (13)	35.7 (5)	26.9 (7)	24.7 (55)
	Fall	53.9 (55)	71.8 (28)	57.1 (24)	57.1 (8)	61.5 (16)	58.7 (131)
	*Response rate***	*93.6 (102)*	*97.5 (39)*	*93.3 (42)*	*82.4 (14)*	*74.3 (26)*	*90.7 (223)*

*Percentages cumulate down a column based on number of responses from each region.
**Percentages for response rate are based on total of 246 compost users.
***Participants could select more than one option; therefore, percentages for each region may exceed 100%.

TABLE 6. Treatment status of BSAs by type of crop in a needs assessment survey to assess current practices of organic farmers on use of biological soil amendments in a multi-regional U.S. study

		Regional distribution of farms* % (count)					
		West	Midwest	Northeast	South	No answer	Total
Fresh Produce	Raw	13.7 (14)	52.7 (29)	14.1 (9)	43.3 (13)	10.0 (2)	24.7 (67)
	Raw & composted	10.8 (11)	5.5 (3)	12.5 (8)	6.7 (2)	5.0 (1)	9.2 (25)
	Composted	65.7 (67)	38.2 (21)	64.1 (41)	40.0 (12)	65.0 (13)	56.8 (154)
	Heat treated	9.8 (10)	3.6 (2)	9.4 (6)	10.0 (3)	20.0 (4)	9.2 (25)
	*Response rate***	*53.4 (102)*	*44.7 (55)*	*74.4 (64)*	*63.8 (30)*	*13.6 (20)*	*45.6 (271)*
Produce to be cooked or processed	Raw	20.2 (18)	54.9 (28)	15.3 (9)	48.0 (12)	9.1 (2)	28.0 (69)
	Raw & composted	12.4 (11)	9.8 (5)	20.3 (12)	8.0 (2)	13.6 (3)	13.4 (33)
	Composted	61.8 (55)	27.5 (14)	61.0 (36)	28.0 (7)	68.2 (15)	51.6 (127)
	Heat treated	5.6 (5)	7.8 (4)	3.4 (2)	16.0 (4)	9.1 (2)	6.9 (17)
	*Response rate***	*46.6 (89)*	*41.5 (51)*	*68.6 (59)*	*53.2 (25)*	*15.0 (22)*	*41.4 (246)*
Forage crops for livestock	Raw	54.2 (26)	73.2 (60)	56.3 (18)	64.3 (9)	47.6 (10)	62.4 (123)
	Raw & composted	12.5 (6)	6.1 (5)	18.8 (6)	7.1 (1)	9.5 (2)	10.2 (20)
	Composted	31.3 (15)	17.1 (14)	25.0 (8)	28.6 (4)	42.9 (9)	25.4 (50)
	Heat treated	2.1 (1)	3.7 (3)	0	0	0	2.0 (4)
	*Response rate***	*25.1 (48)*	*66.7 (82)*	*37.2 (32)*	*29.8 (14)*	*14.3 (21)*	*33.2 (197)*
Fruit and nut trees	Raw	27.1 (26)	50.0 (17)	20.0 (7)	33.3 (4)	11.8 (2)	28.9 (56)
	Raw & composted	14.6 (14)	5.9 (2)	11.4 (4)	16.7 (2)	5.9 (1)	11.9 (23)
	Composted	53.1 (51)	41.2 (14)	62.9 (22)	33.3 (4)	70.6 (12)	53.1 (103)
	Heat treated	5.2 (5)	2.9 (1)	5.7 (2)	16.7 (2)	11.8 (2)	6.2 (12)
	*Response rate***	*50.3 (96)*	*27.6 (34)*	*40.7 (35)*	*25.5 (12)*	*11.6 (17)*	*32.7 (194)*

*Percentages cumulate down a column based on number of responses from each region.
**Percentages for response rate are based on total of 594 participants.

included: destroy or discard produce, waiting or quarantine, plowing produce in or composting it, relocating manure, reporting or testing, washing and keeping produce for self-use.

Recordkeeping and information sources

Between 41.8% to 69.5% of the participants responded to a question regarding recordkeeping on the use of BSAs *(Table 7)*. More than 90% reported usually or always keeping records about the type and source (92.9%, 328/353), crop type and location (93.5%, 377/403), and date of application (92.0%, 380/413) *(Table 7)*. Records of application rate and time interval between application and raw manure application and harvesting were usually or always kept by 88.0% (250/284) of the participants *(Table 7)*. Records related to the use of BSAs were kept for two years or less by 14.6 % (62/423), 3–5 years by 33.3 % (141/423), and five years or more by 52% (220/423) of the respondents. Only 30.1% (128/414) of the respondents reported that customers and/or markets requested a third-party audit for production practices.

Seventy-four percent (440/594) of producer participants responded to a question about being familiar with FSMA regulations and the use of animal manure. Of those, 69.8% (307/440) were familiar with FSMA regulations and the

TABLE 7. Record-keeping habits of producers in a needs assessment survey to assess current practices of organic farmers on use of biological soil amendments in a multi-regional U.S. study

		Record-keeping frequency for % (count)*					
		West	Midwest	Northeast	South	No answer	Total
Type and source/ supplier	Never	3.2 (5)	1.3 (1)	1.5 (1)	5.9 (2)	7.7 (1)	2.8 (10)
	Rarely/Sometimes	3.2 (5)	8.8 (7)	1.5 (1)	5.9 (2)	0	4.2 (15)
	Usually/Always	93.7 (148)	90.0 (72)	97.1 (66)	88.2 (30)	92.3 (12)	92.9 (328)
	*Response rate***	*82.7 (158)*	*65.0 (80)*	*79.1 (68)*	*72.3 (34)*	*8.8 (13)*	*59.4 (353)*
Crop and location of application	Never	4.0 (7)	1.0 (1)	1.2 (1)	2.8 (1)	7.7 (1)	2.7 (11)
	Rarely/Sometimes	2.3 (4)	6.1 (6)	4.8 (4)	2.8 (1)	0	3.7 (15)
	Usually/Always	93.6 (162)	92.9 (91)	94.0 (78)	94.4 (34)	92.3 (12)	93.5 (377)
	*Response rate***	*90.6 (173)*	*79.7 (98)*	*96.5 (83)*	*76.6 (36)*	*8.8 (13)*	*67.8 (403)*
Date of application	Never	2.9 (5)	1.0 (1)	2.4 (2)	0	7.1 (1)	2.2 (9)
	Rarely/Sometimes	5.7 (10)	7.7 (8)	3.6 (3)	8.1 (3)	0	5.8 (24)
	Usually/Always	91.4 (160)	91.3 (95)	94.0 (78)	91.9 (34)	92.9 (13)	92.0 (380)
	*Response rate***	*91.6 (175)*	*84.6 (104)*	*96.5 (83)*	*78.7 (37)*	*9.5 (14)*	*69.5 (413)*
Time interval between raw manure application and crop harvest	Never	8.8 (10)	3.9 (3)	8.5 (5)	3.8 (1)	11.1 (1)	7.0 (20)
	Rarely/Sometimes	3.5 (4)	7.9 (6)	5.1 (3)	3.8 (1)	0	4.9 (14)
	Usually/Always	87.7 (100)	88.2 (67)	86.4 (51)	92.3 (24)	88.9 (8)	88.0 (250)
	*Response rate***	*59.7 (114)*	*61.8 (76)*	*68.6 (59)*	*55.3 (26)*	*6.1 (9)*	*47.8 (284)*
Verification records of time/ temperature/ turning for compost	Never	29.2 (35)	47.2 (25)	30.6 (15)	40.0 (6)	18.2 (2)	33.5 (83)
	Rarely/Sometimes	15.0 (18)	18.9 (10)	22.4 (11)	13.3 (2)	9.1 (1)	16.9 (42)
	Usually/Always	55.8 (67)	34.0 (18)	46.9 (23)	46.7 (7)	72.7 (8)	49.6 (123)
	*Response rate***	*62.8 (120)*	*43.1 (53)*	*57.0 (49)*	*31.9 (15)*	*7.5 (11)*	*41.8 (248)*

use of animal manure as a soil amendment. The question about impact of the FSMA produce safety rule related to use of soil amendments containing raw manure was answered by 70.5% (419/594) of the participants; 27.0% (113/419) of respondents reported that it will have an impact, 39.3% (165/419) said no impact, and 33.7% (141/419) said that the impact was unknown.

A question about the sources of information regarding the use of raw manure and compost and associated food safety risks was answered by 71.7% (426/594) of the respondents. The top five sources of information were: extension agent (39.0%, 166/426), university publications or books (37.3%, 159/426), Internet (36.2%, 154/426), crop consultant or advisor (30.3%, 129/426), and federal or state agencies (e.g., National Resource Conservation Service, USDA, State Departments) (24.9%, 108/426). Food safety (85.2%, 350/411) and good agricultural practices (84%, 353/420), compost (70.9%, 290/409), and treatment of raw manure (65.8%, 270/410) were considered very important or important areas for training on use of BSAs.

DISCUSSION

The information gained from this multi-regional needs assessment survey adds to the growing body of literature on U.S. organic and sustainable agriculture. This survey aimed to characterize and describe agricultural practices related to the use of biological soil amendments of animal origin that may be related to pre-harvest food safety in organic fresh produce. Agricultural practices related to the use of raw manure, compost and treatment of raw manure varied among the regions. Variability on those practices may affect the microbial and physicochemical properties of manure and the soil as well as the survival of pathogens *(30)* and therefore the potential food safety risks. However, despite the effort to extend this survey nationwide, the data presented herein focused on 8 top organic production states (California, Wisconsin, Pennsylvania, Washington, Ohio, Vermont, Maine, and Minnesota).

The majority of the participants in this survey represent small-medium size farms (66% of the participants reported farm size less than 80 acres) with an annual revenue of less than $500,000 *(41)* (84.4% of the participants) *(Table1)*. Similar findings were reported in a survey conducted by the National Sustainable Agriculture Coalition (NSAC), where 70% of the farmers reported operating on less than 50 acres and using untreated BSAAOs in produce fields *(27)*. In the present survey, between 47% to 92% of the participants *(Table 2)* reported using BSAAOs (i.e., raw manure, treated manure and compost) containing animal manure (e.g., aged or stacked manure, slurries, poultry and litter, animal bedding), less than 60% reported using BSAAOs on produce crops typically consumed fresh and 50.1% using them on produce crops consumed cooked or heat processed *(Table 3)*. These findings reflect the reliance on use of BSAAOs in organic agriculture in the U.S. *(35)*, particularly on small to medium-size farms. The multiple benefits of adding BSAAOs to soils (improving the essential nutrient content of the soils over time, replenishing soil organic material, enhancing soil water retention and soil structure) are well documented *(32, 33, 35)*. Of note, in this study, more than 80% of respondents reported soil health, tilth, and nutrient management as the main reasons for use BSAs with raw manure.

The use of untreated or raw manure in fresh produce may increase the risk of crop contamination and consequently the risk of foodborne illness among consumers when best practices are not followed *(17, 35)*. In the present study, when farmers were specifically asked about the use of raw manure, 58.3% of them reported the use of raw manure *(Table 3)*, with poultry, cattle and horses being the main animal sources of raw manure. Similarly, in the NSAC study, poultry was reported being the most common type of manure used *(27)*. The majority of those reported that the manure was produced on-site (73.3%), stored in a pile (79.6%) and not treated (71.8%) on the property before application *(Table 4)*. The nutrient and microbiological characteristics of animal-based soil amendments (i.e., untreated manure) depend on several factors such as livestock species (e.g., cattle, poultry, small ruminants, and swine), production system, animal diet, bedding material (amount and type), manure management (e.g., storage, application rate), and type of manure (e.g., solid slurry or liquid) *(16, 30)*. For instance, cattle are natural reservoirs of *E. coli* O157:H57, and high concentrations of this pathogen are found in feedlot and dairy cattle manure *(5, 38)*, whereas poultry farms often harbor *Salmonella* spp. and *Campylobacter* spp. *(1, 3)*. Horse manure was identified as the potential source of environmental contamination (including soil) by *Salmonella* Oranienburg in a case study in coastal Northern California *(23)*. A study in the UK assessed the prevalence of foodborne pathogen agents in several livestock manure samples *(19)*. Manure from younger animals (e.g., calves less than 3 months of age, piglets or lambs) had higher prevalence and levels of *Campylobacter* spp. and *E. coli* O157, while manure containing any form of bedding had a lower prevalence of both pathogenic *Listeria* spp. and *Campylobacter* spp. *(19)*. The type of diet also affected the prevalence and levels of foodborne pathogens *(19)*. The roughage type can affect the survival of *E. coli* O157:H7 and *Salmonella* Typhimurium, with a more rapid decline in the population of these two pathogens in cow manure derived from a straw diet than in manure derived from grass silage plus maize silage *(13)*. Similarly, *E. coli* O157:H7 survived longer in feces of steers fed with corn than in feces of steers fed with barley *(2)*. Regionally, animal diet and raw manure sources might depend on the common production industry system in the region. The U.S. Environmental Protection Agency (EPA) estimates that 1.1 billion tons of manure are produced annually, with 83% contributed by cattle, 10% by swine, and 7% by poultry *(44)*. California, Texas and Minnesota are among the top 10 states producing manure per unit farmland area *(44)*; the majority of the manure is land applied in forage crops, but the percentage used in fresh vegetable crop production is not known.

The persistence and survival of pathogens in soil and manure-amended soils depends on animal source, pathogen, manure management, soil properties, including inherent edaphic (e.g., type of soil), crop management (e.g., cover crop), and environmental (e.g., season, ambient temperature, rainfall, humidity, and sunlight) conditions *(5, 10, 11, 16, 19, 26, 31, 35, 37)*. Survival of these pathogens in manure and soil environments varies greatly. *Salmonella* can survive up to 1.5 years *(48)*, and *E. coli* O157:H7 can survive in bovine feces from 49 to 126 days *(14)*, and *L. monocytogenes* is ubiquitous and persists in many farm environments *(22)*, even over seasonally cold/freezing temperatures. In a greenhouse trial, *E. coli* (including nonpathogenic and attenuated *E. coli* O157:H7) survival varied on soil amended with different animal manures (i.e., poultry litter, dairy manure liquids, horse manure amended, and unamended)

and soil type (i.e., sandy loam, clay loam, and silt loam) *(34)*. Poultry litter amended soils supported higher *E. coli* survival at higher populations than did dairy manure liquids and horse manure *(34)*.

Regarding the interval between storage and application, treatment type and application frequency, a large range of practices were reported. Graham et al. (2014) reported that the persistence of nonpathogenic *E. coli* in manure-amended soils was affected by application method (i.e., surface-applied manure, and tilled-in manure), air temperature and soil moisture *(15)*. Moreover, Hutchison et al. (2004) showed that the decline of zoonotic pathogens (i.e., *E. coli* O157:H7, *Salmonella* spp. and *Campylobacter* spp.) was significantly more rapid for livestock wastes when they were left on the soil surface *(20)*.

In an open-ended question in this study about the treatment method, some producers mentioned aging and composting. It was evident that composting and aging were used as interchangeable terms in some of the responses. Many farmers reported aging manure as a composting process. On-farm composting practices of naturally contaminated manure is likely to be highly variable; producers may adopt stockpiling of manure *(5)*. This stockpiling and manure aging may not achieve the same benefits of storage, handling, land application, fly reduction and microbial reduction as managed composting *(5)*.

This multi-regional survey documented a wide range of on-farm manure management practices (sources, storage, type of treatment, application method, application time, etc.), which may affect the survival and persistence of pathogens in amended soils. Therefore, mitigation practices to decrease the risk of potential microbial contamination to fresh produce crops resulting from application of untreated manure must take into account the multiple farming factors (e.g., agricultural and livestock practices) and specific characteristics of the region such as environmental factors, geological factors, and growing seasons (year-round versus seasonal) that may be involved. The variation affects the biological and physicochemical properties of manure and soil and hence the survival of the pathogens *(30)*. Additionally, cultural traditions related to the use of raw manure may vary in different farming families and their communities, which could influence their openness to changing to safer practices, such as composting, to reduce microbial contamination.

However, based on the findings of this survey, a relatively small percentage (24.7%) of respondents reported using raw manure in fresh produce production *(Table 6)*. In contrast, a much higher percentage (62.4%) of respondents reported using BSAAOs on forage crops for livestock *(Table 6)*. These non-produce operations using raw manure may still represent a risk of cross-contamination (runoff, drift, equipment, etc.) if in close proximity to fresh produce fields and orchards *(24)*. Compost was the most common soil amendment used in fresh produce (56.8%) *(Table 6)*, although the extent to which this category may also include unmanaged composting practices (e.g., stacked or aged manure without the benefit of validated compost processing) is uncertain. For those using compost as BSAs, the main source of composting was commercial, but 74.6% reported on-site composting using windrow turning or aerated static piles *(Table 5)*. The United States Department of Agriculture (USDA) National Organic Program (NOP) requires that compost be produced through a process in which the initial C:N ratio is between 25:1 and 40:1 and maintained at a temperature between 131°F and 170°F for 3 days using an in-vessel or static aerated pile systems, or for 15 days using a windrow with a minimum of five times turning *(43)*. The same composting parameters are required in the Produce Safety Rule of the Food Safety Modernization Act *(45)*. Although we didn't asked for details regarding the composting process (ratio of C:N, temperature record keeping), the responses regarding manure treatment and composting methods and use should be interpreted with caution, as in an open-end question, farmers considered aging manure in a pile as a composting process. In a survey conducted by the National Sustainable Agriculture Coalition (NSAC), untreated and aged manure were reported as the most common BSAOOs used in fresh fruit and vegetable production *(27)*. Moreover, the manure source was reported as on-farm by 77.3% of the respondents in the present study *(Table 5)*. Identical findings were observed in the NSAC survey (61.9%) *(27)*. The lack of consistency regarding composting methods (composting versus aging) and use of untreated manure reflect the need for on-farm physical-chemical treatments of raw manure (including composting) and scale-adapted processes suitable for different size production systems. Moreover, 49.6% of the farmers indicated they usually or always keep records of verification of time, temperature, and turning for compost *(Table 7)*. However, because treatment processes and management practices that effectively inactivate pathogens in animal manure will reduce the risk of human foodborne illness linked to produce consumption *(5)*, compliance and treatment methods should be reinforced and adapted to specific agricultural systems. Development of educational and training materials on the difference between composting methods, using a scientifically valid controlled process versus stacking of untreated manure, is needed for both growers and NOP auditors to be in compliance with the Produce Safety Rule Act and NOP *(45)*. Additionally, we identified the need for more grower-level training that specifically addresses composting requirements such as those related to record-keeping, pile turnings and frequency, C:N ratio, moisture, and other physical, chemical, or biological aspects.

The direct and indirect use of raw manure in crop fields increases the potential for exposure to foodborne pathogens and consequently can become a food safety hazard *(29)*. The prevention of contamination of foodborne pathogens is based on time intervals between the application of untreated manure and crop harvesting. The USDA National Organic Program (NOP) rule requires a 120-day interval between

incorporation of raw manure into the soil or side-dressing of crops and harvest of crops with edible portions in direct contact with the soil and a 90-day interval for crops with the edible portion not in direct contact with the soil *(42)*. Among respondents using raw manure in fresh produce fields, more than 90% responded that they wait either 90 or 120 days post-application of untreated manure before crop harvest. In contrast, the NSAC survey reported a much lower percentage followed the NOP application intervals for the use of raw manure; this may be explained by a lower participation of USDA-certified organic farmers (32%) in the NSAC survey *(27)* as compared with the present study (82% of the participants were USDA-NOP organic certified).

Prevention of pre-harvest contamination of fresh produce is achieved by implementation of good agricultural practices, including practices to reduce microbial concentration in manure and preventive control of cross-contamination during farming and harvesting of fresh produce. The implementation of good agricultural practices requires good recordkeeping, written SOPs and farm worker training. In general, less than 65% of the farmers reported having a written protocol of SOPs or GAPs to reduce the risk of foodborne pathogens being transmitted from raw manure, designated specific equipment and tools for handling raw manure, and proof of worker training about food safety. Moreover, a variety of practices were reported regarding minimizing run-off from stored raw manure and corrective actions taken in case of accidental raw manure contamination of produce fields. About 74% of the participants reported being familiar with FSMA regulations and use of animal manure. However, these findings should be interpreted with caution because of the low response; there is a need to develop educational materials addressing recordkeeping and mitigation strategies to reduce the risk of contamination of fresh produce in systems using BSAAOs, mainly untreated manure.

CONCLUSIONS

The findings from this study suggest that current practices related to the use of BSAAOs and food safety risks in organic agriculture vary by region. Respondents represented primarily six major organic production regions and tended to be small-medium sized farms growing on less than 80 acres. Among those producing commodities covered under the Produce Safety Rule, the most common raw manure types used were poultry, cattle and horse. Of concern, some farmers appear to use the terms treatment, composting and aging as equivalent processes for aged, and stacked animal manures. Important training and education needs were identified related to the specific methods required to produce scientifically validated compost containing raw manure under the Produce Safety Rule. This survey provides a framework for risk mitigation strategies to reduce microbial contamination of fresh produce in systems using BSAAOs, mainly untreated manure in organic agriculture.

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