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Assessing Connections in an Agricultural Community Using Social Network Analysis

Cheryl Beseler[a,*], **Annie J. Keeney**[b,c], **Robyn Garratt**[d], **Alix Wertheimer**[e], **Lorann Stallones**[a]

[a]Psychology Department, Colorado State University, Fort Collins, Colorado, USA

[b]School of Social Work, San Diego State University, San Diego, California, USA

[c]High Intermountain Plains Center for Agricultural Health and Safety, Colorado State University, Fort Collins, Colorado, USA

[d]School of Public Health, Colorado State University, Fort Collins, Colorado, USA

[e]School of Public Health, Colorado State University, Fort Collins, Colorado, USA

Abstract

Agricultural workers experience higher rates of injury and illness than other occupational groups. NIOSH-supported agricultural centers in the U.S. are funded to reduce injury and illness but require effective partnerships with other agricultural organizations to achieve this goal. Our purpose was to understand the structure of agricultural organization connections within six states in the western U.S., including how different types of organizations connect to one another, and specifically where the High Plains Intermountain Center for Agricultural Health and Safety (HICAHS) is positioned in the agricultural organization network. An electronic survey was distributed to contacts within organizations that had a previous history with HICAHS leadership and advisory board members. The survey asked respondents about their position in the organization, years with the organization and frequency of contact in the past year. A social network analysis was undertaken to assess the connections between agricultural organizations using measures of centrality (density, closeness, betweenness), cliques, clusters, and brokers. A two-tier structure was identified with a core group of 21 organizations and a peripheral group of 30 organizations. Influence was centered in the core group as evidenced by high centrality scores with minimal bridging between organizations. HICAHS was on the periphery, but on the cusp of being in the core. Agricultural producers, agricultural extension and insurance companies were central in the network. Centers are in a unique position to promote collaboration with stakeholders. The social network analysis identified missing connections that need further development in order to address agricultural safety and health.

Keywords

social networks; cluster analysis; agriculture

[*]Correspondence: chbeseler@unmc.edu.

Disclosure statement

Authors have no disclosures to report.

Introduction

Agricultural workers experience higher rates of adverse health outcomes and fatalities than do workers in other occupations. According to the Bureau of Labor Statistics, farmers and the farm workers industry had a fatality rate of 24/100,000 in full-time equivalent (FTE) workers in 2017 compared to a fatality rate of 3.5/100,000 among FTE workers in all industries.[1] Non-fatal occupational injuries and illnesses in these industries again ranked high, having a reportable case rate of 5.0/100 workers compared to 3.1/100 workers in all industries.[1] These statistics highlight the high risk of fatal and non-fatal injuries and illnesses among workers in the agricultural industry, and the importance of health and safety research aimed at reducing these rates.

The United States Centers for Agricultural Safety and Health (Agricultural Centers) program was established in response to a Centers for Disease Control and Prevention (CDC)/National Institute of Occupational Safety and Health (NIOSH) Agricultural Health and Safety Initiative in 1990. Currently, eleven Agricultural Centers are distributed regionally throughout the United States with the purpose of protecting agricultural workers by disseminating research through education and prevention projects. In 1991, the High Plains Intermountain Center for Agricultural Health and Safety (HICAHS) was established to encompass Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming.

The success of the Agricultural Centers depends on partnerships among academia, industry, government, agricultural operators/owners, employees, and stakeholders engaged in agricultural safety and health. Collaboration is needed, yet research gaps exist in understanding relationships between and among stakeholders in the agricultural community. This study investigates the use of a social network analysis to assess how connections among organizations can be a central tool in promoting and advancing agricultural worker health and safety.

Social network analysis is an underutilized yet valuable approach in assessing social connectivity among agricultural organizations. Social network analysis can be used to understand the network's density, connectedness, centralization, cliques and subgroups. Although identifying and building partnerships is fundamental to effective program implementation,[2] to the best of our knowledge, only four agriculture-related social network analyses have appeared in the literature. Ramirez (2013) utilized this tool to evaluate the influence of information exchange within a social network on a farmer's decision to adopt water conservation technology.[3] Findings revealed that daily interactions of subgroups within professional farming networks played an essential role in technology adoption, but not all farmers have access to organizational affiliations from which community knowledge often stems.[3] Similarly, a social network analysis was used to better understand how farmers exchange knowledge and discuss science within their networks.[4] The network consisted of 17 farmers and 5 scientists and was a repeated-measures design to assess how farmers grew their networks and to assess how information was exchanged after participating in a lamb-finishing farming experiment.[4] Results revealed strong ties and a decentralized network; farmers increased their contacts by 53.6% following the experiment primarily through contacts with social peers.[4]

The Central States Center for Agricultural Safety and Health (CS-CASH) published two of the four agriculture-based social network analysis studies. Cramer, Araz, and Wendl (2017) applied a social network analysis to gauge affiliations between external stakeholders and leaders of CS-CASH that had occurred in the 12 months prior to the study.[5] Center leaders most commonly networked with other researchers, and, while such collaborations were positive, stakeholder diversity within a network may be essential for focused goal attainment.[5] Most recently, Almeida et al. (2019) of CS-CASH used a social network analysis to evaluate how their work with respiratory protective gear could influence product diffusion among agricultural workers through communication with external stakeholders.[6] Similar to the research of Ramirez (2013) mentioned above, this second CS-CASH study also aimed to understand transfer of knowledge on innovative technology by way of social networks. Findings mirrored their first social network analysis study,[5] implicating the need for a more diverse stakeholder network.

Social network analysis offers a promising, multidisciplinary approach to examining relational data between and among individuals or organizations, while exploring real-world connections, or lack thereof, among stakeholders.[7] Utilizing established relationships of well-integrated organizations throughout existing social networks can help extend network reach and enhance the potential to connect with organizations currently missing. Certain organizations within a network may be more centrally positioned, and therefore better able to serve as a channel to convey knowledge to other, less centrally positioned organizations. Direct and indirect paths between organizations (nodes) can be strengthened as the flow of information and influence gains efficiency.

Although previous work using a social network approach has examined the diffusion of information in a network and stakeholder engagement with Agricultural Center investigators, it has not been applied to understand the structure and characteristics of organizations in an Agricultural Center's region. The objectives of this study were to (1) understand the structure of the network of agricultural organizations within the six-state HICAHS region, (2) assess the strength of connections between different types of agricultural organizations and how they interact with one another, and (3) assess the connectedness of HICAHS to organizations that are centrally located in the network.

Methods

Participants

In 2018, key HICAHS personnel and advisory board members (n = 42) were asked to provide organization names and contact people for any agricultural entity they had contact with in the past year. An initial list of 104 organizations was provided to the HICAHS personnel in a survey and they were asked to identify any organizations they had contact with. This list was acquired through an exhaustive search of all agricultural organizations and agriculture-related groups in the HICAHS region. Subsequently, a survey of 15 additional key HICAHS personnel were surveyed and asked about whether they had contacted a given organization or whether that organization had contacted them. These results produced 84 network contacts within the HICAHS region representing 41 different organizations with contact names; 33 of these contacts representing 51 organizations

responded to the social network analysis survey. When different people in the same office of an organization were provided, only one contact was surveyed. We retained multiple names in the same organization if they were in different divisions, which occurred with the Colorado Department of Health and Environment. The response rate was 80%. Ten organizations that did not respond were retained in the analysis because of known contacts with HICAHS and with other organizations who responded. The discrepancy between 41 contacts and 51 organizations is because we assumed bidirectionality in the network. Bidirectionality means that if organization A reported contact with organization B, then B was assumed to have had contact with A. The 33 survey respondents reported being with the organization a mean of 15.6 years (standard deviation = 10.5, range 1–40 years). All data were collected under the approval of the Colorado State University Institutional Review Board.

Measures

An electronic survey was distributed via e-mail to each of the contacts to collect information about social connectivity. We asked the name of the respondent, their organization and how many years the respondent had been working at the organization. In terms of organizational connections, respondents were asked the frequency of interaction with any of these other organizations (once per month, several times per year, once per year, less than once per year, not sure) and the frequency of contact with any particular individual within each of these organizations (same responses as above). A follow-up survey reminder was sent out 1 month after the initial request. The organizations were classified into 11 subgroups: academic research center (n = 1), agriculture, forest, and fisheries industries (n = 10), cooperative extension (n = 10), government (n = 7), health and safety services (n = 4), insurance companies (n = 5), K-12 education (n = 5), medical care (n = 1), NIOSH-funded occupational safety and health centers (n = 3), public health (n = 2) and agricultural producers (n = 3).

Data analysis

A binary 51 × 51 adjacency matrix was created from the responses. Each cell was coded as 1 if a contact was reported and 0 otherwise. A second 51 × 51 matrix was created using the frequency of contacts as the weight in each cell. A network graph was created to display the connections between the organizations. Each node in the graph represents an organization and the edges are the connections between the nodes. Path length is measured by how many distinct nodes must be traversed to get from one node to another using the shortest possible path. If the minimum average path length equals one it means every organization is connected to every other organizations. Measures of centrality were used to describe how nodes were connected, i.e., how prominent and important they were in the network. There are a number of ways to measure who is at the center of a network. We calculated overall degree centrality and betweenness centrality for the network as a whole. We used centrality measures degree, closeness, and betweenness for each organization within the network. Degree is the number of direct connections to all other nodes. Closeness is the sum of the path lengths of the shortest path between a node and all other nodes in the network. It is a measure of how easy it is to get from one node to another. A node with a lower closeness value than a different node is closer to every other node than a node with a larger closeness

value. Betweenness is a measure of how well a node bridges to another node. A higher betweenness measure indicates a critical role in the network because the node is an intermediary on more paths than other nodes and acts as a bridge to others. Organizations with a high betweenness measure have many connections to other organizations and is influential in the network. Density measures interconnectedness and is the number of links in the network expressed as a percentage of all possible connections. Component distribution was used to assess whether any parts of the network were disconnected from the other parts of the network (holes). We also examined cliques and hierarchical clustering within the network. Cliques are subgroups of organizations where each organization is connected to every other organizations. Hierarchical clustering was based on path length between pairs of nodes such that nodes close together form a cluster. This measure represents the number of common connections shared by two organizations.

We used brokerage analysis to investigate our second research question to better understand how different types of organizations interacted with one another.[8] The analysis was done using both a binary matrix and a contact frequency matrix. A brokerage analysis examines the role of mediators between organizations of the same type as itself (in-groups) or organizations of a different type from itself (out-groups). Coordinators connect two in-groups such that all three agents are of the same type. Representatives connect an out-group to an in-group. An itinerant broker connects two out-groups. A gatekeeper links an in-group member to an out-group member and a liaison links two out-groups together that are both different than itself. The brokerage equations produce means and standard deviations that can be used to compute standardized z-scores for significance testing. In these analyses, we used $z > 2.58$ for a confidence level of 99% for acting as a certain type of broker between two organizations due to the large number of connections being tested.

Analysis was conducted in Gephi and R. Gephi software was used to create the network graph displaying organization connections by the eleven subgroup classifications. A radial axis layout was used to group nodes by subgroup classification in axes circulating outwards from a central circle. Each axis was color-coded corresponding to the given subgroup classification. Within each axis grouping, nodes were ordered by degree, with the organization having the highest degree within a given subgroup classification positioned closest to the central circle. Node size was also ranked by degree, with the larger nodes of higher degree within the network.

Results

The agricultural network formed a two-level structure with an inner core and a peripheral group The network contained 51 organizations (nodes) and 795 connections (edges). When examining a binary measure of connection (yes/no), the network formed a central core of 21 organizations and an outer circle of 30 organizations (Figure 1). The degree centralization was 35.6%, reflecting the presence of the core group of organizations connected to many others on the periphery. The overall betweenness measure was only 0.009, indicating that there were few instances of an organization acting as a bridge to a different organization, again indicating two levels. The overall density of the network, a measure of network cohesiveness, was 0.624, which means that 62.4% of the organizations were connected. The

average length of all paths in the network was 1.39. A component analysis showed only a single component consisting of all 51 organizations. On average an organization showed just over one connection, supporting the lack of “bridging” organizations. Dairy 1 was the least connected organization with a degree of 4 and was not connected to any of the centrally situated organizations. Comparing the observed graph to a number of randomly generated graphs showed that the pattern observed is unlikely to have occurred by chance. There is clearly an underlying relational mechanism driving the observed hierarchical structure.

The dendrogram, which displays the hierarchical clustering in the network, showed three larger clusters of size 21, 12, and 9 and two smaller clusters of size 4 (Figure 2). The average clustering coefficient was 0.71 and is higher than expected if it were random. There are two distinct branches in the dendrogram, with the most central organizations in one branch and the peripheral organizations in the other. It is apparent that within states, many organizations share connections. Cooperative Extension organizations also show clustering across states. For example, North Dakota and South Dakota Extension share connections, as do Colorado State University Extension and Montana Extension.

Table 1 shows the organization, the type of organization and three measures of centrality (betweenness, degree, closeness). The largest cliques identified in the network included 16 organizations and the same 14 organizations occurred in all cliques. Two of the organizations in the cliques were not in the inner circle (Governor’s Office and Wyoming Extension); the remaining 14 were. Interestingly, HICAHS was in eight cliques and the National Beef Cattlemen’s Association was in the other eight cliques. HICAHS clustered with the National Beef Cattlemen’s Association indicating that they share many connections, although they are not directly connected (Figure 2).

The structure of the network remained the same when assessing the frequency of the network connections. The density centralization was 2.43 suggesting that the frequency of contact was on average once or twice per year. Closeness remained the same, as did average path length, betweenness, and clique structure.

The strength of connections between different types of agricultural organizations and how they interact with one another

The overall degree of the network using the classifications was 31.2, slightly lower than the degree using individual organizations. Several classifications were sparsely populated making their degrees zero or one. Of those with greater representation, the most connected were the agricultural industry organizations followed by agricultural extension and government. Within the various groupings of organization types, some were more connected with each other than with others (Figure 3). The exception to this was the schools and another Agriculture Center. Agricultural producers had a high degree of connectedness, as did the various agriculture, forestry and fisheries industries, and public health departments. What was evident from this analysis is that Agriculture Research Centers are not as integrated into the network as they could be.

The brokerage analyses showed that 33 of 51 organizations (64.7%) acted as itinerant brokers meaning that they were more likely to bridge two similar organizations different

from themselves and 27 of 51 (52.9%) acted as liaisons where the organization bridged two different types of organizations, both dissimilar to itself. Only six organizations acted as coordinators, 12 acted as representatives and 17 acted as gatekeepers. Six organizations acted as all types of mediators and were identified as cooperative extension (3), government (2) and a single agricultural producer (Stock Growers Association). The brokerage measure for the entire network showed that the liaison role was the strongest with a standardized *z*-score of 10.6; all other scores were less than 3. Most mediating connections were among dissimilar types of organizations. The results were similar when the analysis was conducted using the frequency of connections as a measure of the strength of connections.

HICAHS was on the periphery of the network and was connected to safety and health organizations but limited in scope to the state in which it operates

HICAHS was on the periphery of the network with 25 nearest neighbors. The HICAHS betweenness value was 13.6; 22 of 51 organizations had greater influence in the network than HICAHS. The HICAHS degree was 25, slightly below the network average of 31. The HICAHS closeness measure was 0.67, just below the network average of 0.75. HICAHS was connected to Extension Services in Colorado, Wyoming, Montana; three insurance companies; three dairy producers and the Western States Dairy Producers; the Colorado Department of Public Health and Environment; Agribeef, the Livestock Association and the Logging Association.

Discussion

The agricultural network formed a two-level structure with an inner core and a peripheral group

The network can be described as “small-world” with a short average path length, the presence of cliques, and a relatively high average clustering coefficient (0.71).[9,10] The clustering coefficient means that about 70% of all possible triads were connected and the components analysis showed that no group of organizations were disconnected from the network.

The hub and spoke type of network structure with 21 organizations in the hub group and 31 organizations forming the spokes is considered efficient and stable. The average lengths of all paths in the network was 1.39, so it requires fewer than two steps to connect every organization to every other organization, or fewer than two degrees of separation in the network. This type of network grows by preferential attachment where new nodes in the network link to nodes of higher degree first. These results were nearly identical whether a binary adjacency matrix was used or whether the dichotomous contacts was replaced by frequency of contacts. The strength of the connection may not have been adequately captured by using the frequency of the contact. As in the Cramer et al. (2017) paper, the type of collaboration or level of influence might be better at capturing strength of collaboration.

Understanding the structure of the network and how the network is likely to grow provides insight into where new connections should be made. Knowing that the network is in a

configuration that is efficient and stable reduces the costs of making new connections and ensures that information can flow through the network smoothly.

The strength of connections between different types of agricultural organizations and how they interact with one another

The interactions of organizations by type exhibited heterophily, meaning that organizations were most likely to connect to those different from themselves. Brokers are important in networks because they have greater access to information, they can filter information and they act to refer others inside the network. It was rare for a class of organizations to be connected to members of its own type. The same results held whether the analysis was based on a binary measure or on frequency of contact. Either frequency of contact was not a good measure of the strength of the connection or participants do not recall accurately the frequency of the contact. This result was consistent when assessing individual network organizations or type of organization.

In the context of agriculture, heterophily is understandable. Governmental agencies, insurance companies, producers, and agricultural extensions are contacted for their expertise and assistance from mostly outside organizations. The result is information and knowledge flow among certain types of organizations. This is likely an indicator that the network is working effectively in providing assistance to those who need it, especially given the structure of the overall network where many direct connections exist, and all organizations are connected.

HICAHS was on the periphery of the network and was connected to safety and health organizations but limited in scope to the state in which it operates

For the most part, the connections occurred where there were ongoing projects with the connected organization. Relationships existed with the groups most involved with worker safety and health, such as the Colorado Department of Health and Environment and insurance companies, but HICAHS was not connected with any other state departments of health in the broader region. Outreach to Utah, North Dakota and South Dakota is needed. Funding research proposals from academic and community organizations in these states would help build partnerships. HICAHS, although not in the core group of organizations, was on the cusp of being in the core group. Additional outreach to both core and periphery organizations is necessary to improve the strength of the network and connections with important stakeholders and partners.

As expected, there was a lack of connection in North Dakota and in South Dakota, but fewer connections in Utah than expected. HICAHS does not have as strong a presence in North Dakota and South Dakota partly because of its remote location, but also because it is part of the region of two other agricultural centers, the Central States Center for Agricultural Safety and Health (CS-CASH) and the Upper Midwest Agricultural Safety and Health Center (UMASH); HICAHS has had greater activity in Utah that is not reflected in the results.

HICAHS had only 25 of 51 possible connections. It is surprising that there were connections missing because the initial contacts came directly from key HICAHS personnel. Possibly, individuals within organizations were connected, but there may be lack of awareness of the

organization the individuals represent. As in the Cramer et al (2017) findings, HICAHS key personnel may be better connected with other academic researchers and not recognized as often by agricultural organizations in the public sector. Future efforts should be aimed at strengthening connections outside of academia with the goal of promoting the translation and transfer of research. Building relationships with health departments, agricultural producers, and agricultural extension can improve dissemination of research and increase the flow of information from those forming the ”hub” to those in the “spokes.” Strategic planning including building partnerships, outreach, and community-initiated projects should be included as potential targets for expansion.

Promoting worker health and safety requires comprehensive engagement throughout the network. There may be overlap in activities of different organizations involved in improving worker health and safety, which can lead to inefficient delivery of services and information. An important role of Agricultural Centers is to provide a link between organizations engaged in agricultural production and those engaged in improving the health and safety of the workers. Based on this study, it is evident that work is needed to enhance the connections between the producer organizations, extension activities and HICAHS. Further, attention needs to be paid to states where the connections are less robust than in Colorado and Wyoming, as noted above. The most connected organizations in the HICAHS region were Extension and education; other Agricultural Centers for safety; and cattle, dairy, and pork producers and organizations that support agriculture.

This study represents a preliminary assessment of the network of organizations that are involved in agriculture and the role of one Agricultural Safety Center within the overall network. There was evidence of a strong network with robust ties within the inner grouping of organizations and another group of organizations that interacted but not with the same strength as those on the inner circle. HICAHS was part of this outer circle of organizations engaged with agriculture. This may well represent the overall nature of the organizations involved in the inner circle, where the services focus on production and supporting economic aspects of the agricultural enterprise. Those organizations engaged with worker safety may be closely aligned with each other, such as the health department and other academic researchers, while being somewhat removed from the other organizations. This understanding presents an opportunity for the Agricultural Centers to develop methods for strengthening ties with producer organizations and Extension in order to better support the mission of promoting health and safety among agricultural workers. This also supports taking a systems approach to tackling health and safety and ensuring it is done with more emphasis on the economic benefits that result from having healthy workers.

Future directions

In an environment of scarce resources, it is always important for organizations who share concerns to work together. The Agricultural Centers are in a unique position to assist in developing robust collaborations between stakeholders engaged in agriculture. Through using the preliminary work done with this social network analysis we have identified some specific gaps that can be addressed through purposeful outreach to those groups involved in

the productivity and economic side of agriculture and linking more of the HICAHS activities to align with the goal of improving productivity through improved health and safety.

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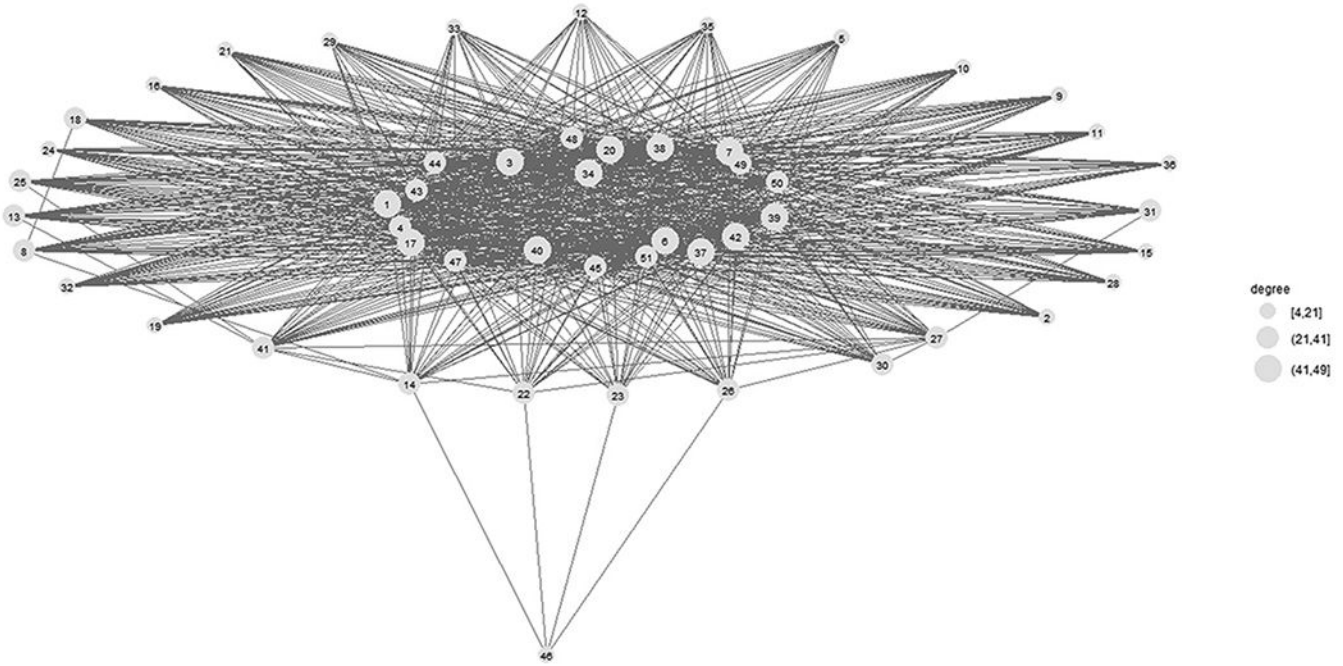

Figure 1.

The network of 51 organizations in the High Intermountain Plains Center for Agricultural Health and Safety (HICAHS) showing a two-tiered structure with nodes divided into three levels of degree indicating the number of direct connections with other organizations in the region, 2018

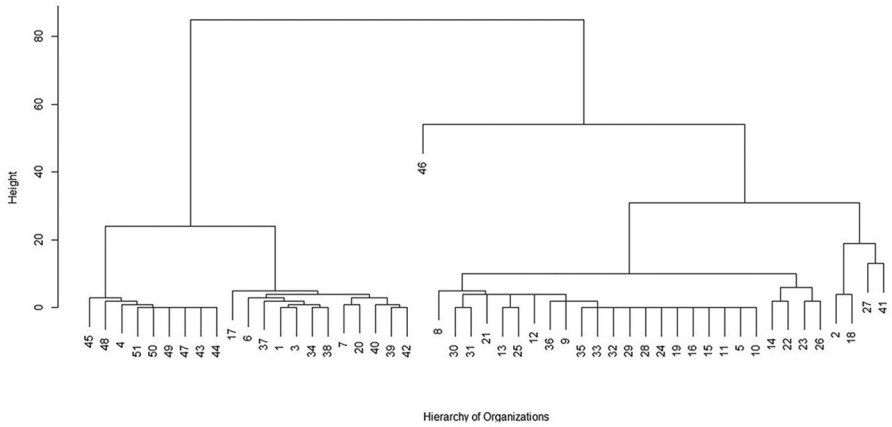

Figure 2.

A dendrogram of the 51 agricultural organizations in the High Intermountain Plains Center for Agricultural Health and Safety (HICAHS) region showing how they cluster within the network, 2018

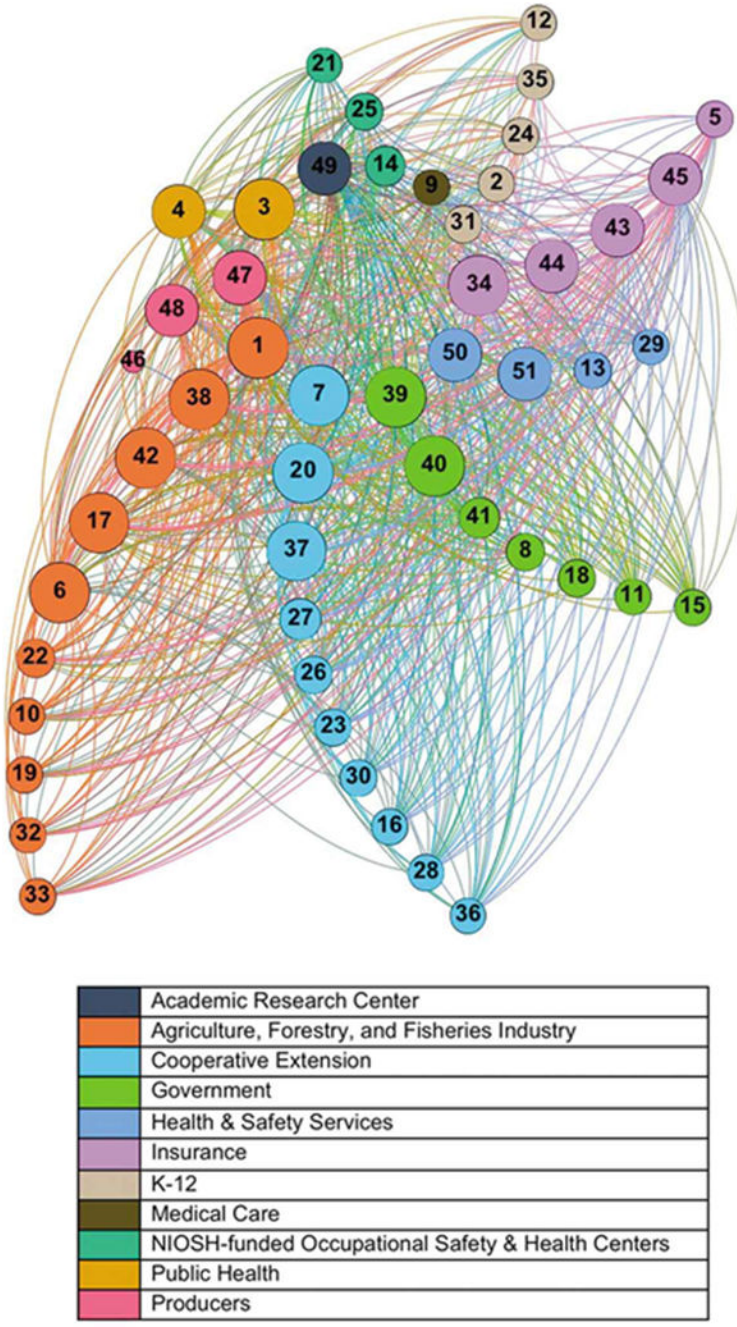

Figure 3.

The structure of the 51 organizations in the High Intermountain Plains Center for Agricultural Health and Safety (HICAHS) region classified by organization type and degree of connectedness, 2018

Table 1.

Organizations in the high intermountain plains center for agricultural health and safety (HICAHS) region, the type of organization and measures of centrality, 2018

Number	Organization	Organization Type	Betweenness	Degree	Closeness
1	Agribeef	Ag Industry	21	49	0.83
2	School District 1	K-12	0.91	21	0.47
3	CDPHE1	Public Health	21	49	0.83
4	CDPHE2	Public Health	20.1	41	0.85
5	Farm Bureau 1	Insurance	0.91	21	0.63
6	Livestock Association	Ag Industry	19.5	48	0.82
7	CSU Extension	Cooperative Extension	21	49	0.83
8	Weed District 1	Government	0.97	23	0.65
9	Healthcare	Medical Care	0.91	21	0.61
10	Dairy Max	Ag Industry	0.91	21	0.63
11	Weed District 2	Government	0.91	21	0.63
12	School District 2	K-12	0.71	20	0.61
13	Great Plains Center for Ag H&S	Health & Safety Services	0.91	22	0.63
14	HICAHS	NIOSH-funded	13.6	25	0.67
15	Weed District 3	Government	0.91	21	0.63
16	4 H 1	Cooperative Extension	0.91	21	0.63
17	Logging Association	Ag Forestry Industry	19.5	48	0.82
18	Natural Resources Conservation Service	Government	0.91	22	0
19	Pork Producers	Ag Industry	0.91	21	0.63
20	MT Extension	Cooperative Extension	21	49	0.83
21	MAP ERC	NIOSH-funded	0.91	20	0.62
22	National Cattlemen’s Beef Association	Ag Industry	12.5	24	0.66
23	ND Extension	Cooperative Extension	11.6	22	0.64
24	School District 3	K-12	0.91	21	0.63
25	Rocky Mountain Center for Occup & Env Health	NIOSH-funded	0.91	22	0.63
26	SD Extension	Cooperative Extension	12	23	0.65
27	WY Extension	Cooperative Extension	1.56	27	0.56
28	4 H 2	Cooperative Extension	0.91	21	0.63
29	AgrAbility 1	Health & Safety Services	0.91	21	0.63
30	Agricultural Experiment Station	Cooperative Extension	0.91	22	0.63
31	Association for Agricultural Education	K-12	0.91	22	0.63
32	Beef Council	Ag Industry	0.91	21	0.63
33	Cattlemen’s Association	Ag Industry	0.91	21	0.63
34	Farm Bureau 2	Insurance	21	49	0.83
35	Future Farmers of America	K-12	0.91	21	0.63
36	UT Extension	Cooperative Extension	0.91	20	0.62

Number	Organization	Organization Type	Betweenness	Degree	Closeness
37	Weld County Extension	Cooperative Extension	20.8	48	0.83
38	Western States Dairy Producers Trade Association	Ag Industry	21	49	0.83
39	Department of Agriculture	Government	21	49	0.83
40	Department of Workforce Services	Government	21	49	0.83
41	Office of Governor	Government	1.31	26	0.54
42	Stock Growers Association	Ag Industry	21	49	0.83
43	Insurance company 1	Insurance	20	41	0.85
44	Insurance company 2	Insurance	20	41	0.85
45	Insurance company 3	Insurance	18.6	40	0.83
46	Dairy 1	Producers	0.26	4	0.42
47	Dairy 2	Producers	20	41	0.85
48	Dairy 3	Producers	20	40	0.83
49	One Health CSU	Academic Research Center	20	41	0.85
50	LDS	Health & Safety Services	20	41	0.85
51	AgrAbility 2	Health & Safety Services	20	41	0.85