

**Identifying and Prioritizing Training Needs Related to Controlled Environment
Agriculture Using a Borich Needs Assessment Approach**

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Abstract

Controlled environment agriculture (CEA), including hydroponics, aquaponics, and vertical farming, has gained attention as a strategy to enhance food system resilience, resource efficiency, and year-round production. However, the technical, biological, and economic complexity of CEA systems presents challenges for those responsible for education, Extension, and implementation. The purpose of this study was to identify and prioritize training needs related to CEA using a systematic needs assessment approach. Guided by human capital theory, the Borich Needs Assessment Model was used to examine discrepancies between stakeholders' perceived importance of key CEA domain areas and their perceived need for additional training. Data were collected through an online questionnaire administered to agricultural educators, Extension professionals, and CEA practitioners in two USDA-NIFA project implementation states. Mean weighted discrepancy scores (MWDS) were calculated to rank training priorities across CEA domains. Results indicated that system design and infrastructure, crop production, pest and disease management, and economic decision-making represented the highest priority training areas, reflecting substantial perceived gaps. Marketing and post-harvest domains exhibited comparatively smaller discrepancies. Findings provide empirical guidance for Extension, educational, and professional development efforts aimed at strengthening workforce capacity for effective CEA implementation.

Introduction and Theoretical Framework

Introduction

Agricultural systems worldwide are facing increasing pressure due to climate variability, land and water constraints, labor shortages, and the need to supply fresh food to growing populations (FAO, 2025). In response, controlled environment agriculture (CEA), including hydroponics, aquaponics, and vertical farming, has gained attention as an innovative approach to food production that enables year-round cultivation through highly controlled, technology-intensive management of growing conditions (Heuvelink et al., 2025; Dohlman et al., 2024). By regulating factors such as light, temperature, humidity, and nutrient delivery, CEA systems offer opportunities to improve resource efficiency, reduce production risk, and support food production closer to consumers, while minimizing dependence on external climatic variability (Benke and Tomkins, 2017).

Despite this promise, the adoption and sustained implementation of CEA systems remain limited and uneven. Prior research has identified several structural and operational barriers, including high capital costs, energy demands, system complexity, and uncertainty regarding economic viability (Li et al., 2025; Aborujilah, 2025; Beacham et al., 2019). Beyond these challenges, evidence suggests that gaps in education and training represent an additional, yet comparatively underexamined, constraint on effective CEA implementation. A recent USDA-NIFA-funded national assessment documented widespread gaps in CEA-related education and workforce preparation, highlighting limitations in the availability of accessible, context-specific training (GLASE Consortium, 2025). Consistent with these findings, stakeholders frequently report difficulty obtaining reliable education and training related to system design, crop production, pest and disease management, environmental monitoring, and economic

decision-making (Burritt et al., 2025). Without adequate preparation and support in these areas, even well-resourced CEA initiatives may struggle to operate effectively or scale sustainably.

These challenges have important implications for agricultural education and workforce development systems. Agricultural educators, Extension professionals, industry practitioners, and lead producers are increasingly expected to support CEA-related learning, adoption, and decision-making across diverse contexts (Kozai et al., 2020; Fox & Garner, 2022). However, many agricultural education and outreach systems were historically developed around conventional, field-based production models, and may lack the instructional capacity and training tools needed to address the interdisciplinary and technology-intensive nature of CEA systems (GLASE Consortium, 2025). Because these groups play key roles in shaping CEA knowledge diffusion, adoption decisions, and peer learning, strengthening their capacity through targeted education and training is essential for effective CEA implementation.

Research in agricultural education and Extension consistently emphasizes that effective programming should be grounded in systematic assessments of stakeholder-identified needs rather than assumptions about what learners require (Borich, 1980; McKillip, 1987; Witkin & Altschuld, 1995). However, despite growing interest in controlled environment agriculture, there remains limited empirical evidence that systematically identifies and prioritizes training needs across key CEA domain areas for building capacity among educators, Extension professionals, and other CEA stakeholders. Given the interdisciplinary nature of CEA, spanning plant sciences, engineering, environmental control, data analytics, and business management (Kalantari et al., 2018; Kozai et al., 2020), there is a clear need for evidence-based approaches that identify where education and Extension training efforts are most needed.

Theoretical Framework

This study drew on human capital theory and needs assessment theory. Human capital theory informed the focus on training and competency development for effective controlled environment agriculture (CEA) practice, while needs assessment theory guided the systematic identification and prioritization of training needs.

Human Capital Theory

Human capital theory conceptualizes education and training as investments that enhance individuals' knowledge, skills, and competencies, thereby improving their capacity to perform effectively within professional roles (Becker, 1964; Goldin, 2016). Although rooted in economics, the theory has been widely applied in education, workforce development, and Extension contexts to examine how training contributes to professional capacity (Roco et al., 2013; Rivera & Alex, 2008).

In agricultural systems, human capital development has become increasingly important as production practices grow more technologically complex and knowledge-intensive. In the context of CEA, required capacities extend beyond general agricultural knowledge to include system design and management, environmental monitoring, crop production, pest and disease management, and economic and operational decision-making (Kozai et al., 2020). From a human capital perspective, effective CEA implementation depends not only on access to infrastructure and technology but also on stakeholders' ability to apply specialized knowledge and skills.

Needs Assessment Theory

Needs assessment theory provides a systematic approach for identifying gaps between current conditions and desired outcomes (Witkin & Altschuld, 1995). In agricultural education and Extension, needs assessments are widely used to inform program planning, prioritize instructional content, and allocate limited resources based on stakeholder-identified needs rather than assumed priorities (McKillip, 1987; McCawley, 2009).

Purpose and Objectives

The purpose of this study was to identify and prioritize training needs across key controlled environment agriculture (CEA) domains using a structured needs assessment approach. This study was conducted in Indiana and South Carolina part of a USDA-NIFA-funded initiative focused on strengthening CEA education and workforce capacity.

The specific objectives of the study were to:

1. Assess stakeholders' perceived importance and need for additional training in key CEA domain areas and
2. Prioritize CEA domain areas for training using mean weighted discrepancy scores (MWDS)

Methods/Procedures

Research Design

This study employed a non-experimental, descriptive research design using a cross-sectional online survey to conduct a needs assessment related to controlled environment agriculture (CEA). A needs assessment approach was selected to systematically identify and prioritize training needs by examining discrepancies between stakeholders' perceived importance of, and perceived need for, additional training across key CEA domains. Training needs were assessed across five CEA domain areas representing core areas of knowledge and skill required for effective CEA implementation and support. This design is appropriate for informing agricultural education and Extension program planning by capturing stakeholder perceptions at a single point in time.

Population and Sample

The target population consisted of stakeholders involved in controlled environment agriculture, including agricultural educators, Extension professionals, and individuals engaged in CEA-related production or industry roles. These groups were selected due to their involvement in CEA education, implementation, or knowledge dissemination and their potential influence on training and workforce development efforts.

The study was conducted in Indiana and South Carolina, which served as implementation states for a USDA-NIFA-funded project focused on strengthening education, Extension, and workforce capacity related to controlled environment agriculture. Recruitment efforts targeted stakeholders working in CEA, urban agriculture, or horticulture, and agricultural resource management within these states. Project managers in each implementation state provided listservs containing potential respondents aligned with the study purpose.

Participants were recruited using purposive sampling, targeting individuals actively engaged in CEA-related education, Extension, production, or industry roles (Teddlie & Yu, 2007). A total of 183 individuals were contacted through the listservs, and 60 fully completed responses were retained for analysis. To be included, respondents were required to complete all Likert-type items. Several partial respondents indicated limited familiarity with controlled environment agriculture, which prevented survey completion, underscoring the specialized and emerging nature of the Controlled Environment Agriculture (CEA) concept.

Table 1 summarizes the demographic characteristics of the final sample. Respondents represented a range of professional roles, including agricultural teachers, Extension educators, and CEA practitioners. The mean age of participants was 40.48 years (SD = 11.80), and the average professional experience across roles, defined as teaching experience for educators, Extension programming experience for Extension professionals, production experience for growers, and relevant technical or managerial experience for industry professionals, was 15.76 years (SD = 12.01). The sample was predominantly White and non-Hispanic, with representation across genders and educational attainment levels.

Table 1: Demographic characteristics of the final sample (n = 60)

Variable		Frequency	Percent	Mean	SD
Education level	4-year college or less	23	38.33		
	Associate degree	2	3.33		
	Masters degree	27	45.00		
	PhD degree	8	13.34		
Gender	Male	25	41.67		
	Female	32	53.33		
	Third-gender	1	1.67		
	Not preferred	2	3.33		
Age				40.48	11.80
Profession	Extension educator/extension specialist/4-H educator	16	26.67		
	Ag teacher	32	53.33		
	Full-time/ part-time farmer/ Industry	12	20.00		
Professional experience		-	-	15.76	12.01

Ethnic or cultural identity	Asian, South Asian, or Pacific Islander	1	1.67
	Black or African American	4	6.67
	Hispanic or Latino	3	5.00
	White (non-Hispanic)	48	80.00
	Other	3	5.00
	Prefer not to say	1	1.66

Instrumentation

Data were collected using a questionnaire administered through the Qualtrics survey platform. The instrument was developed using a needs assessment framework and informed by a review of relevant literature on controlled environment agriculture, agricultural education, and workforce development. Items were designed to reflect key CEA domain areas relevant to effective system implementation and support.

Content validity was established through expert review before survey administration. Experts with experience in CEA research, agricultural education, and Extension programming evaluated the instrument for item clarity, relevance, and alignment with the study objectives and domain structure. Feedback from the review process was used to refine item wording, ensure appropriate domain coverage, and improve overall instrument clarity.

The final instrument assessed training needs across five CEA domains: system design and infrastructure; crop production; pest and disease management; economics; and marketing or post-harvest management. For each item, participants provided two ratings using four-point Likert-type scales: perceived importance (1 = not important to 4 = extremely important) and perceived need for additional training or support (1 = no need to 4 = strong need).

Internal consistency reliability was assessed through a pilot study involving 16 respondents who were not included in the final sample. Cronbach’s alpha coefficients were calculated for each domain for both importance and need scales. Reliability estimates are reported in Table 2 and indicate strong internal consistency across domains. The harvesting category was removed before final data collection due to comparatively lower reliability in the pilot study.

Table 2: Reliability measures of the Needs Assessment instrument (n = 16)

Category	Items	Cronbach’s value-Needs	Cronbach’s value-Importance
CEA system	13	0.931	0.928
Crop production	9	0.891	0.884
Pest & disease management	7	0.868	0.873

Economics	6	0.911	0.934
Marketing or post-harvest management	8	0.964	0.971

Data Collection

Following institutional review board (IRB) approval, data were collected between July and September 2025 using an online survey administered via Qualtrics. Data collection procedures used multiple follow-ups in accordance with the Tailored Design Method (Dillman et al., 2014) to enhance response rates and reduce survey error. This approach included multiple contacts with potential respondents, personalized communication, a visually clear and user-friendly survey design, and explicit communication regarding study purpose and confidentiality protections.

An initial email invitation was distributed to potential participants, followed by multiple reminder messages to non-respondents in accordance with IRB approval. Participation was voluntary, and all responses were collected anonymously.

Data Analysis

Descriptive statistics, including means and standard deviations, were calculated to summarize participants' perceptions of the importance of CEA domain areas and their perceived need for additional training or support. Preliminary data management was conducted using Microsoft Excel, and statistical analyses were performed using IBM SPSS Statistics (*Version 29*).

Training priorities were identified using the Borich Needs Assessment Model (Borich, 1980). For each respondent, a discrepancy score was calculated by subtracting the perceived need rating from the perceived importance rating for each item. Discrepancy scores were then weighted by the corresponding importance rating. Mean weighted discrepancy scores (MWDS) were calculated by averaging weighted discrepancy scores across respondents for each item and domain area.

Domain areas were subsequently ranked according to MWDS values, with larger scores indicating relatively higher priority training needs. This approach emphasizes stakeholder-identified gaps and supports systematic prioritization of training content. Although alternative needs assessment models, such as the Ranked Discrepancy Model (RDM), have been proposed (Narine & Harder, 2024), the Borich model remains widely applied in agricultural education and Extension research and was appropriate for prioritizing CEA training needs in this study.

Results/Findings

Training needs related to controlled environment agriculture (CEA) were identified and prioritized using the Borich (1980) needs assessment model. Mean weighted discrepancy scores (MWDS) were calculated for each CEA domain, with larger values indicating greater divergence between perceived importance and perceived need for additional training. Results are presented by major CEA domain areas to support interpretation and inform programmatic decision-making. When examined at the domain level, MWDS values revealed variation in perceived training needs, indicating differential priorities for capacity development across CEA-related areas.

CEA System Design and Infrastructure

Results for CEA system design and infrastructure (Table 3) indicated the largest discrepancies in managing heating and cooling systems ($MWDS = 0.94$) and understanding foundational CEA concepts ($MWDS = 0.78$), highlighting gaps in environmental control and applied system understanding. In contrast, familiarity with system types and integration into new spaces showed minimal discrepancies. These findings suggest a need for applied, system-level training focused on environmental regulation and operational decision-making.

Table 3: Participants Perception of Importance and Levels of Needs on CEA System Design

Criteria	Importance Mean (SD)	Needs Mean (SD)	MWDS
Setting up CEA systems	3.37 (0.76)	3.22 (0.81)	0.49
Tools required for installing CEA systems	3.23 (0.72)	3.03 (0.86)	0.65
Climate control setting options in CEA systems	3.40 (0.72)	3.20 (0.78)	0.68
Fundamental concepts of CEA systems	3.35 (0.71)	3.12 (0.78)	0.78
Standard Operating Procedures (SOPs) in CEA systems	3.30 (0.85)	3.15 (0.86)	0.50
Sustainable production practices in CEA systems	3.32 (0.85)	3.17 (0.87)	0.50
Optimal size of CEA system	3.03 (0.82)	2.88 (0.83)	0.46
Ideal cover material for enclosure	3.07 (0.80)	2.90 (0.86)	0.51
Types of CEA systems	3.07 (0.71)	3.02 (0.77)	0.15
Managing heating and cooling systems	3.33 (0.73)	3.05 (0.83)	0.94
Desired internal microclimate in CEA systems	3.25 (0.70)	3.08 (0.83)	0.54
Technical knowledge of CEA cultivation	3.35 (0.71)	3.18 (0.91)	0.56
Integration of CEA systems on rooftops, new spaces, etc.	2.98 (0.87)	2.93 (0.86)	0.15

Crop Production

Results for crop production in Table 4 highlight gaps related to managing plant responses under controlled conditions. The largest discrepancies were associated with temperature management ($MWDS = 0.77$) and identification of nutrient toxicity symptoms ($MWDS = 0.67$), reflecting challenges in diagnosing and responding to crop stress in enclosed environments.

Moderate discrepancy was also evident for planting techniques ($MWDS = 0.59$) and recognition of stress-related symptoms, suggesting a need for training that supports diagnostic reasoning and physiological understanding. However, areas related to nutrient concentrations exhibited smaller discrepancies, indicating their closer alignment between perceived importance and level of need. Overall, these results indicate demand for advanced, problem-oriented crop management training tailored to the unique dynamics of CEA systems.

Table 4: Participants' Perception of Importance and Levels of Needs on Crop Production

Criteria	Importance Mean (SD)	Needs Mean (SD)	MWDS
Planting techniques in CEA systems	3.23 (0.72)	3.05 (0.81)	0.59

Crops suitable for CEA cultivation	3.48 (0.65)	3.35 (0.68)	0.46
Nutrient management in CEA-grown crops	3.52 (0.68)	3.40 (0.59)	0.41
Fertilizer or nutrient concentrations for CEA-grown crops	3.45 (0.67)	3.37 (0.64)	0.29
Nutrient deficiency symptoms of CEA-grown crops	3.40 (0.72)	3.28 (0.69)	0.40
Nutrient toxicity symptoms of CEA-grown crops	3.37 (0.64)	3.17 (0.81)	0.67
Temperature management in the CEA system	3.28 (0.85)	3.05 (0.83)	0.77
Water management in CEA cultivation	3.23 (0.74)	3.07 (0.84)	0.54
Technical knowledge on pre-breeding technologies for CEA-grown crops	2.82 (1.02)	2.67 (0.97)	0.42

Pest and Disease Management

Within pest and disease management, discrepancies clustered around areas requiring diagnostic and intervention-related skills. The largest MWDS scores as shown in Table 5, were associated with pest identification ($MWDS = 0.71$) and pest management strategies specific to CEA systems ($MWDS = 0.61$), suggesting uncertainty in managing pest pressures in enclosed production environments.

Disease identification and management showed moderate divergence, while agro-chemical mixing ($MWDS = 0.26$) exhibited relatively small discrepancies. These patterns indicate that respondents perceive a greater need for training focused on identifying and responding to pest challenges unique to controlled environments, rather than general chemical application practices.

Table 5: Participants' Perception of Importance and Levels of Needs on Pest & Disease Management

Criteria	Importance	Needs	MWDS
	Mean (SD)	Mean (SD)	
Pest identification in CEA-grown crops	3.28 (0.74)	3.07 (0.90)	0.71
Disease identification in CEA-grown crops	3.27 (0.76)	3.10 (0.88)	0.54
Pest management in CEA systems	3.32 (0.70)	3.13 (0.87)	0.61
Disease management in CEA systems	3.33 (0.73)	3.20 (0.86)	0.44
Different agro-chemicals for CEA-grown crops	3.22 (0.72)	3.08 (0.85)	0.43
Agro-chemical mixing or application in CEA systems	3.08 (0.94)	3.00 (0.99)	0.26
Optimum levels of agro-chemical application	3.27 (0.71)	3.08 (0.93)	0.60

Economics of CEA Systems

Table 6 reflects notable discrepancies between perceived importance and perceived need within the economics domain. The greatest discrepancies were observed for evaluating economic returns ($MWDS = 0.85$), understanding cost structures ($MWDS = 0.59$), and conducting benefit–cost analyses ($MWDS = 0.56$).

These results suggest that while economic considerations are widely recognized as critical for CEA decision-making, respondents perceive gaps in their ability to assess financial feasibility and long-term viability of CEA systems. In contrast, record keeping ($MWDS = 0.37$) and awareness of economic barriers ($MWDS = 0.21$) showed comparatively smaller discrepancies. Overall, findings underscore the need for applied economic analysis and financial decision-support as salient areas of training in CEA contexts.

Table 6: Participants' Perception of Importance and Levels of Needs on Economic Aspects

Criteria	Importance <i>Mean (SD)</i>	Needs <i>Mean (SD)</i>	MWDS
Operational costs of CEA production	3.22 (0.87)	3.03 (0.92)	0.59
Economic returns from CEA production	3.42 (0.81)	3.17 (0.99)	0.85
Economic barriers related to CEA farm development & operation	3.20 (0.82)	3.13 (0.87)	0.21
Benefit-cost ratio of CEA produce	3.38 (0.78)	3.22 (0.85)	0.56
Infrastructure costs in CEA	3.32 (0.79)	3.17 (0.89)	0.50
Record-keeping for CEA management	3.17 (0.83)	3.05 (0.95)	0.37

Marketing and Post-Harvest Management

Compared to other domains, marketing and post-harvest items (Table 7) exhibited relatively small divergence between perceived importance and training need. With the exception of modest discrepancies related to location selection ($MWDS = 0.41$), most items showed minimal gaps.

This pattern suggests that respondents do not currently view marketing or post-harvest considerations as primary constraints relative to technical, biological, or economic challenges. Moreover, findings indicate that stakeholders place greater emphasis on production and decision-making aspects related to CEA practice.

Table 7: Participants' Perception of Importance and Levels of Needs on Marketing & Post-harvest Aspects

Criteria	Importance <i>Mean (SD)</i>	Needs <i>Mean (SD)</i>	MWDS
Marketing options for CEA produce	2.97 (0.90)	2.98 (0.85)	-0.05
Marketing strategies for CEA produce	2.95 (1.00)	2.92 (0.96)	0.10
Accessibility to markets	3.07 (1.01)	3.02 (0.98)	0.15
Product pricing strategies	3.08 (0.79)	3.02 (0.87)	0.21
Storage	3.13 (0.85)	3.03 (0.90)	0.31
Location selection guidance	3.07 (0.88)	2.93 (0.95)	0.41
Care during transportation of the CEA produce	3.02 (0.83)	2.97 (0.80)	0.15
Post-harvest management process of CEA-grown crops	3.17 (0.81)	3.10 (0.80)	0.21

To summarize patterns across CEA domains, mean perceived importance, mean perceived need, and MWDS were calculated at the domain level (Table 8). Domain-level MWDS values ranged from 0.18 to 0.52, reflecting variation in the magnitude of perceived training gaps across domains. Based on MWDS rankings, system design and infrastructure, crop production, pest and disease management, and economic aspects emerged as the highest-priority domains for capacity development in controlled environment agriculture.

Table 8: Participants' Perception of Importance and Levels of Needs on all CEA domains

Criteria	Mean Importance	Mean Needs	MWDS	Rank
CEA system design and infrastructure	3.23	3.07	0.52	1
Crop production	3.31	3.16	0.50	2
Pest & disease management	3.25	3.10	0.49	3
Economics of CEA systems	3.28	3.13	0.49	4
Marketing & post-harvest management	3.06	3.00	0.18	5

Conclusions and Implications

This study extends existing needs assessment research by systematically identifying and prioritizing training needs in controlled environment agriculture (CEA) using a structured Borich model approach. Findings indicate that training needs are concentrated in technical, biological, and economic domains, reflecting the interdisciplinary complexity of CEA systems and the need for applied, decision-oriented competencies. These results reinforce prior research identifying workforce readiness and applied training capacity as central challenges in the effective implementation of emerging agricultural technologies (Kozai et al., 2020; GLASE Consortium, 2025).

Training needs related to CEA system design and infrastructure were most pronounced in areas requiring environmental control and applied system operation. Stakeholders reported substantial gaps related to managing heating and cooling systems, regulating internal microclimates, and implementing consistent operational procedures. Although environmental regulation was widely recognized as foundational to CEA success, the findings suggest persistent difficulty translating this importance into effective system management without targeted training. This pattern aligns with existing literature emphasizing environmental control as both a defining strength and a continuing challenge of CEA systems due to their technical complexity and sensitivity to operational decisions (Benke & Tomkins, 2017; Kalantari et al., 2018; Kozai et al., 2020).

Results related to crop production further underscore the complexity of managing biological processes within controlled environments. Stakeholders reported notable training gaps associated with temperature regulation and identification of nutrient toxicity symptoms, highlighting challenges in diagnosing and responding to plant stress. Consistent with prior research, these findings suggest that effective CEA crop management requires advanced physiological understanding and adaptive decision-making that differ substantially from conventional field-based production systems (Beacham et al., 2019; van Delden et al., 2021).

Within the pest and disease management domain, participants identified significant gaps related to pest identification and pest management strategies specific to CEA systems. These discrepancies reflect the distinct pest dynamics of enclosed production environments, where altered lifecycles, constrained chemical control options, and rapid population growth can complicate management decisions. The findings suggest that traditional field-based pest management knowledge may not fully translate to CEA contexts, reinforcing the need for CEA-specific integrated pest management training tailored to controlled environments (Jürkenbeck et al., 2019; Burritt et al., 2025).

Economic domain areas emerged as one of the most prominent areas of perceived need. Stakeholders reported substantial discrepancies related to evaluating economic returns, understanding cost structures, and conducting benefit–cost analyses. Although these areas were viewed as essential for decision-making and long-term viability, participants indicated limited preparedness to assess financial feasibility within CEA systems. These findings are consistent with prior studies identifying economic uncertainty and limited financial decision-making capacity as key barriers to CEA adoption, scaling, and sustainability (Beacham et al., 2019; Li et al., 2025).

In contrast, domain areas related to marketing and post-harvest management exhibited relatively smaller discrepancies between perceived importance and training need. This pattern suggests that stakeholders currently view technical, biological, and economic challenges as more immediate constraints during earlier stages of CEA implementation. Similar trends have been observed in Extension needs assessments for emerging production systems, where system performance and economic viability take precedence over downstream market considerations (McCawley, 2009).

Overall, these findings indicate that priority CEA training needs are concentrated in areas requiring applied decision-making, diagnostic capacity, and system optimization. The results underscore the value of structured needs assessment approaches in guiding Extension and workforce development efforts, ensuring that training investments align with stakeholder-identified gaps rather than assumed needs. As CEA continues to expand across educational, Extension, and industry contexts, systematically identifying and addressing these priorities will be critical for supporting effective implementation and long-term system sustainability (Borich, 1980; Witkin & Altschuld, 1995).

Recommendations

Based on prioritized training gaps identified through the Borich needs assessment model, several recommendations are offered to inform controlled environment agriculture (CEA) education, Extension programming, and future research. Training efforts should prioritize system design and infrastructure, crop production, pest and disease management, and economic decision-making, as these domain areas exhibited the largest discrepancies between perceived importance and level of need. Professional development initiatives should emphasize applied, practice-oriented learning that supports environmental control, diagnostic decision-making, and system management. Economic and financial decision-making should be embedded as a core component of CEA training to support informed investment and long-term viability. Finally, future research should further examine how CEA training needs vary across stakeholder groups, regions, and system types, and how these priorities evolve over-time. These findings provide a data-driven foundation for aligning Extension programming and agricultural education curricula with stakeholder-identified workforce needs.

Limitations and Future Research Directions

Limitations should be considered when interpreting the findings of this study. First, data were collected from stakeholders in two implementation states, which may limit generalizability to other geographic contexts with differing CEA infrastructures, market conditions, or policy environments. Second, the study relied on self-reported perceptions of importance and training need rather than objectively measured capacity. While perception-based measures are appropriate for needs assessment research,

future studies could strengthen inference by incorporating observational or performance-based assessments.

Additionally, the modest sample size may have limited the precision of MWDS estimates across domains. Participation was limited to individuals with some familiarity or engagement with CEA or related areas, as several partial respondents reported insufficient awareness to complete the survey. This underscores both the specialized nature of CEA and the need for continued outreach and foundational education. Future research should broaden sampling and examine training needs across system types, adoption stages, and stakeholder groups.

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