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AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES WITH AN EXPERT SYSTEM

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ABSTRACT

An expert system, Aeration System Design (ASD), was developed for the design of aeration systems for farm-sized flat grain storages. ASD requests information about the storage problem from a user and generates a custom design drawing, component specification list, and management recommendations. The knowledge base was derived from publications and experts. ASD represents the first attempt to consolidate aeration system design guidelines and procedures for flat grain storage into an expert system.

ASD uses illustrations to communicate concepts and terminology more clearly with users. A feature of ASD allows an expert to change the design guidelines and factors. For example, alternative methods of determining the layout and length of ducts can be selected. ASD offers the capability of rapidly designing an aeration system and changing design guidelines to study the effects upon the design.

INTRODUCTION

Grain surpluses and government incentives for producers who store grain often result in a temporary shortage of grain storage facilities. Grain producers respond by preparing new and existing structures for flat grain storage. These storages require an aeration system to maintain the quality of grain.

Although design guidelines for aeration systems are available in extension publications, these guidelines are general and are often not applicable to a producer's specific problem. Grain producers often request help from extension agents, who refer the problem to the state extension specialist or other expert. The availability of an expert in aeration system design is often limited and a means is needed to make this expertise available in county extension offices and sales offices of aeration system component suppliers.

The objective of this study was to develop a microcomputer-based aeration system design program (ASD) to simulate the role of an expert in an interactive

session with a grain producer and to design aeration systems for farm-sized flat grain storages. The available knowledge base consists of guidelines and procedures described in engineering handbooks, extension publications, and technical articles in addition to the experience of experts in aeration system design.

Expert opinion was obtained by developing a preliminary version of ASD and applying a structured expert review process with nine experts to review ASD (Watson et al., 1988). Important findings of the evaluation were that given the same problem, aeration system designs differ among experts. Differences in the layout of aeration ducts and determining the length of ducts were attributed to two different design methods and vague guidelines in the literature, respectively.

ASD was developed using the application development model described by Watson et al. (1986). The model divides the development of an application into four components: 1) interview, 2) calculation, 3) design drawing, and 4) management recommendations. The model encourages the selection of software development tools which are best suited for each component. By linking the components, the application executes as one program. Since the result of this study is a computer program, the methodology and discussion of ASD are presented using the same organization as the application development model.

INTERVIEW COMPONENT

The interview component is used to query users about the design problem and educate the user as needed. An interactive program development tool, INTPRO, described by Peterson et al. (1988) was used to implement the interview component. An ASCII text file was prepared for INTPRO to use in executing the interview component. The text file describes the questions, help information, order of screens, consistency checks among responses, and external programs which are used by ASD. Besides information required to size and place aeration equipment, screens were included to request information about the structure to verify post-size requirements. Information screens were described that display the results of intermediate calculations such as post sizing and storage capacity.

Illustrations are used to supplement text and increase the efficiency of communication (figs. 1 and 2). Illustrations are based on line-drawings and digitized slides and have been prepared for black and white, 16 color, and 256 color computer display systems.
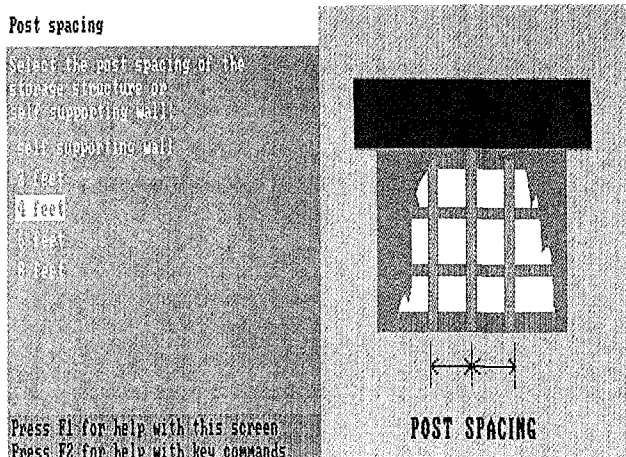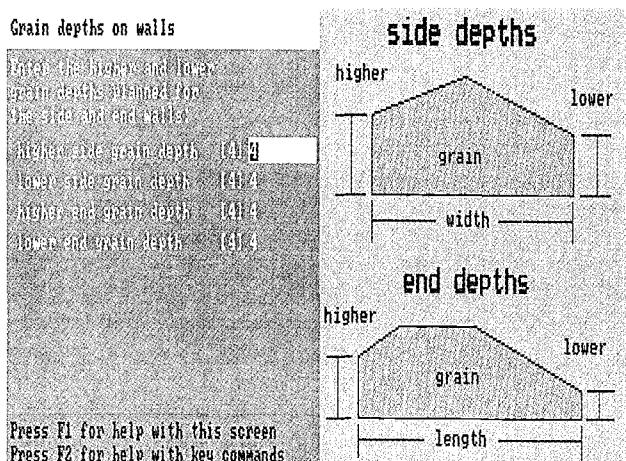
Figure 1–Sample choice screen from ASD.

Figure 2–Sample numeric input screen from ASD.

CALCULATION COMPONENT

The calculation component of ASD is required to generate a component listing and design drawing, and to select appropriate management recommendations. The calculation module was implemented as a separate program written in the "C" programming language and executed by INTPRO. ASCII files are used to convey data between INTPRO and the calculation program.

The calculation component consists of seven procedures, based on the procedure recommended by Holman (1960): 1) post sizing, 2) storage capacity, 3) duct placement, 4) duct length, 5) fan placement and size, 6) duct size, and 7) connector placement and size. The following sections outline the computation approach for these sections. Details of the equations have been presented elsewhere (Watson, 1987).

POST SIZE

The post sizing procedure is included to help the user determine the allowable grain depth on the side walls of the storage structure. The ASD uses post size, spacing, and allowable grain depth data from Irish et al. (1984) and user provided post spacing and grain depth data to determine the minimum post size for the storage structure.

STORAGE CAPACITY

The ASD calculates the grain capacity of the storage and reports it to the user. If needed, the user can alter building dimensions and grain depths to arrive at the desired capacity. The filling angle of the particular grain is used to determine the profile of the grain in storage, based on the user provided dimensions and grain depth at the walls. The default filling angles for the grains included in ASD are: 25° for corn, 28° for soybeans, and 23° for wheat and grain sorghum. The ASD calculates the maximum peak grain depth allowable both widthwise and lengthwise in the storage as follows:

$$D_{peak} = D_{hs} + \frac{W \tan\theta - |D_{hs} - D_{is}|}{2} \qquad (1)$$

where

D_{peak} = peak grain depth, m (ft),
D_{hs} = grain depth at higher side wall, m (ft),
D_{ls} = grain depth at lower side wall, m (ft),
W = storage width, m (ft),
θ = filling angle of particular grain, deg.

The least of the calculated peak grain-depths widthwise and lengthwise in the storage and the maximum piling depth provided by the user is used as the peak grain depth of the storage.

The capacity of a grain storage is calculated by dividing the storage into 12 volumes (Watson, 1987, fig. 3). This method is a refinement of the method suggested by the Midwest Plan Service (1987) in which the grain storage is divided into three volumes. The 12-volume method takes advantage of the computation speed of a computer to estimate capacity of a storage with different grain depths at each wall.

DUCT PLACEMENT

This procedure of the calculation component performs the task of determining the position of ducts in the storage based on air path ratios described by Holman (1960) and Burrell (1974). For example, if the desired air path ratio is 1.5, ducts should be spaced so that the longest air path from a duct to the grain surface is no more than 1.5 times the shortest air path from the same duct to the grain
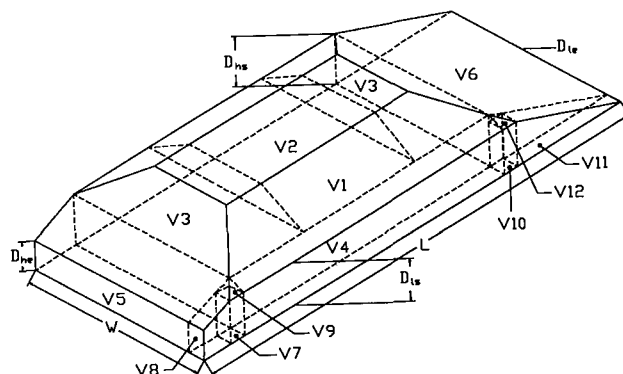

Figure 3–Grain storage divisions used by ASD for volume calculation.

surface. The default air path ratios of ASD are 1.5 for center ducts, 1.8 from an outer duct to the adjacent wall if the grain depth at the wall is 1.5 m (5 ft) or higher, and 2.0 from an outer duct to the adjacent wall if the grain depth at the wall is less than 1.5 m (5 ft). This combination of air path ratios was derived from recommendations of Holman (1960) and Burrell (1974) and was used to generate results similar to the specific guidelines for positioning of ducts based on the size of the storage as recommended by Cloud and Morey (1980), Foster and Tuite (1986), Holman (1960) and Midwest Plan Service (1987). A factor for the minimum depth of grain to aerate (defaults to 1.22 m or 4 ft) is used by ASD to ignore shallower depths of grain. This factor is not in the literature but was suggested by the experts.

The duct placement procedure performs the following steps: 1) places ducts based on the air path ratio, 2) calculates the air path ratio from the first and last ducts to the nearest wall, 3) compares calculated air path ratio to guidelines, and 4) if needed, adjusts the number of ducts and repeats from step 1. The ASD places up to 20 ducts in a storage, starting in the center of the storage, and begins by assuming an even number of ducts. For an even number of ducts, the center of the grain peak is the border of the area aerated by the two center ducts. Although ASD is normally used to determine the number of ducts, the user may specify the number of ducts for ASD to place.

The position of a duct or border is determined by moving it in increments of the placement increment factor (defaults to 7.6 cm or 3 in.) from a previously determined border or duct until the air path ratio is equal to or slightly less than the desired air path ratio. After the ducts are placed, based on the air path ratio for center ducts, the air path ratios from the outer ducts to the adjacent walls are calculated as follows:

$$R_{ap} = \frac{W - P_d + D_w}{D_{sh}} \qquad (2)$$

where

R_{ap} = air path ratio,
W = width of storage, m (ft),
P_d = duct distance from wall, m (ft),
D_w = grain depth at wall, m (ft),
D_{sh} = shortest distance from duct to grain surface, m (ft).

These ratios are compared with the desired air path ratio for an outer duct to the adjacent wall. If the calculated air path ratio is not equal to the desired ratio, the estimated number of ducts is incremented or decremented by one and the duct-placing algorithm is used to place the revised number of ducts. This procedure is repeated until the air path ratios from the outer ducts to the adjacent walls are equal to the desired ratio or until the number of ducts has been both decremented and incremented. The higher number of ducts is used to perform a final duct spacing.

This duct placement procedure requires several hours of an expert's time if ASD is not used, whereas, with ASD results can be generated in seconds. With ASD, an expert can quickly experiment with different inputs and design factors.

DUCT LENGTH

In flat storages, the perforated aeration duct usually does not start at the end of the storage, but is offset into the grain profile. The end points of the duct in the grain storage must be determined to calculate duct length. In determining the end points, air paths through grain should be as equal as possible (Foster and Tuite, 1986). Burrell (1974) recommended that the distance of the perforated duct from the end of the storage plus the grain depth at the end be equal to the longest air path elsewhere in the storage.

Procedures for determining the endpoint of a perforated duct section are vague in the literature and vary among experts. The ASD allows three different methods to determine the end points of a duct. The first method is the default method and sets an end point so that the shortest distance from the duct to the grain surface is equal in both the widthwise and lengthwise directions of the storage. This method is similar to the method described by Burrell, which maintains air path lengths as equal as possible in the deeper sections of the grain storage, but can result in less airflow to shallower sections of a storage.

The second method offsets a duct into the grain by a distance equal to the depth of grain on the end wall of the storage. This method is used by some experts to provide more airflow in the shallower sections of a storage, but can result in more variation of air path lengths than the first method.

The third method uses the first and second methods to determine two end points and a ratio factor to choose an end point which is a compromise between the two methods.

These different methods are provided to allow an expert to adapt ASD to local preferences or experiment with the different methods. The factors involved in the three methods can be customized by an expert as described in the 'Component and Design Factor Customization' section below.

FAN PLACEMENT AND SIZE

Fan sizing consists of determining the number of fans per duct, positioning the fans relative to the duct, and sizing each fan based on the airflow requirement and a static pressure estimate. ASD allows one or two fans per duct. The maximum length of duct served by a fan with ASD is 24.4 m (80 ft.).

An estimate of the static pressure of the grain is calculated according to the American Society of Agricultural Engineers Standard D272.1 (ASAE, 1987) as follows:

$$\frac{\Delta P}{L} = \frac{aQ^2}{\log_e (1 + bQ)} \qquad (3)$$

where

ΔP= pressure, Pa (in. H_2O)
L = bed depth, m (ft),
a = constant for particular grain,
Q = airflow rate, $m^3/s \cdot m^2$ ($ft^3/min/ft^2$),
b = constant for particular grain.

The shortest distance from the duct to the grain surface is used for bed depth (Holman, 1960). Factors for adjusting

static pressure to reflect storage conditions are 1.5 for shelled corn and grain sorghum and 1.3 for soybeans and wheat (MWPS, 1987). The estimated static pressure is increased by 62 Pa (0.25 in. H_2O) for connector (solid duct section) losses and 62 Pa (0.25 in. H_2O) for each tee or elbow in the connector. If the estimated static pressure is still less than 125 Pa (0.5 in. H_2O), the static pressure is increased to this factor, as it is usually the threshold for fan performance data.

The required airflow is based on the user specified airflow rate and the volume of grain served by the duct. The default value for airflow rate is 0.17 m^3/min/ton (0.15 ft^3/min/bu). The same procedure used to calculate the capacity of the entire storage is used to calculate the capacity of the volume served by a duct.

Fan curve data for axial and centrifugal fans from Brook and Harmsen (1982) are stored in the aeration program and used to estimate airflow output of a fan at the estimated static pressure with the following equation:

$$Q_f = a - b * P^2 \qquad (4)$$

where
Qf = fan output, m^3/s (ft^3/min),
a = constant for particular fan,
b = constant for particular fan,
P = pressure, Pa (in. H_2O).

The estimated airflow is increased by 10% as a sizing allowance for accepting lower airflow instead of using the next larger size fan. Although, the 10% factor is not in the literature, it was suggested by experts to minimize the cost of an aeration system. The required airflow is compared with the estimated airflow of available fans, to find the best match. Once a fan is selected, the fan and systems curves are matched to estimate the operating conditions.

DUCT SIZE

Duct size is based on the allowable airflow velocities in the duct and exiting the duct. The aeration program uses 457 m/min (1500 ft/min) (Brook, 1979; MWPS, 1987) maximum airflow velocity in the duct and 7.6 m/min (25 ft/min) (Cloud and Morey, 1980) exit velocity. The maximum velocities were increased by 10% to allow a slight increase in airflow velocity rather than use the next larger duct. The 10% factor is not in the literature, but was chosen based on design practices of experts. Minimum cross-sectional area and surface area of the duct are calculated and the larger of the two calculated diameters is used to specify duct size.

CONNECTOR PLACEMENT AND SIZE

Connector or non-perforated duct sections were placed and sized to channel air from the fan on the outside of the storage to the perforated duct. Connector diameter is determined based on the allowable airflow velocity in the connector of 610 m/min (2000 ft/min) (Foster and Tuite, 1986; Holman, 1960) plus the 10% factor used in sizing ducts.

CALCULATIONS OUTPUT

Once the calculations for an aeration system design have been completed, the calculations component prints a

**Aeration System Component Specifications
for John Doe**

The accompanying floor plan of the grain storage illustrates the placement of the components. Ducts are labeled with numbers and fans are labeled with letters. The following table lists the specifications of each component.

Duct		Fan				
#	size	#	size	cfm*	sp†	connector size
1	12" x 81'	A	12" 0.33hp	1740	0.6	14" x 9'
2	21" x 53'-6"	A	16" 1.50hp	3773	0.5	21" x 23'-3"
3	21" x 53'-6"	A	16" 1.50hp	3773	0.5	21" x 23'-3"
4	12" x 81'	A	16" 0.33hp	1740	0.6	14" x 9'

*cfm – airflow in cubic feet per minute required from fan.
†sp – operating static pressure of the fan in inches of water.

Figure 4–Sample component specification listing generated by ASD.

list of component specifications and writes a drawing specification file. The component specifications are printed in tabular form and include: 1) the diameter and length of each duct, 2) the diameter, horsepower, estimated airflow, and estimated static pressure for each fan, and 3) the diameter and length of the connector (fig. 4). The drawing specification file is used by the design drawing component to generate a floor plan of the design.

COMPONENT AND DESIGN FACTOR CUSTOMIZATION

ASD has provisions for an expert to customize the grain factors, fan and duct specifications, and design guidelines. The grain factors which can be customized are the grain types, angle of repose, airflow factors for the ASAE (1987) static pressure equation, and packing factor. Duct specifications include duct type, sizes, maximum air velocities, static pressure per unit of length, and maximum length of duct from an air source. Fan specifications which can be customized are fan size, horsepower, and performance curve factors used to estimate airflow delivery with equation 4.

Most of the design factors used by the ASD can be customized. Some of the important ones are: 1) the factors and method for determining the length of a duct, 2) the air path ratios for determining the position of ducts in the storage, and 3) the method for estimating static pressure within a duct.

DESIGN DRAWING COMPONENT

Parametric computer aided drafting techniques (Carroll et al., 1987) are used to generate a custom plan for each set of user responses. A separate drawing processor program was written in Pascal. The processor reads a drawing specification file generated by the calculations component and generates a design drawing on the screen (fig. 5).Users have the option of printing the plan or changing inputs to generate a different plan. The drawing processor includes a section of code which describes master drawings of each component which can be combined into a design drawing. The primary master drawings are the storage outline, perforated duct (fig. 6), solid duct, and fan. The master drawings include dimension lines and can be scaled, mirrored, and rotated on the X and Y axes.
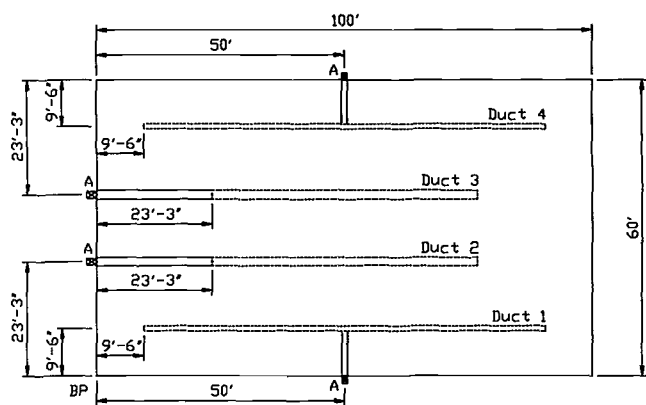
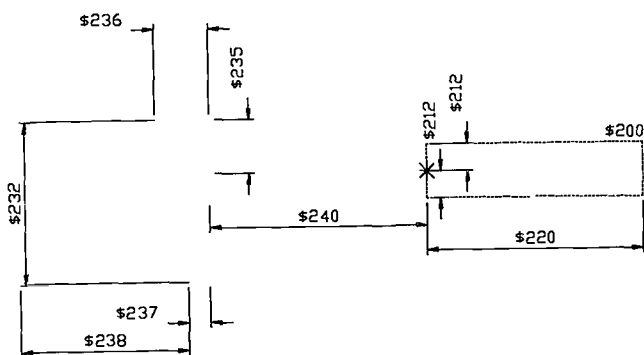Figure 5–Sample aeration system plan displayed and printed for user of ASD.

Figure 6–Master drawing of perforated duct used by design drawing component to generate custom plans.

MANAGEMENT RECOMMENDATIONS COMPONENT

The management recommendations component of ASD was implemented with RECPRO, an application development tool (Peterson et al., 1988). An ASCII file of recommendations and if-then rules for printing the recommendations was prepared for RECPRO. The recommendations listing is divided into four sections: 1) user responses, 2) flat storage comments, 3) specific plan comments, and 4) grain management comments.

The user responses are summarized on the management recommendations printout to relate the plan to a specific problem. Flat storage comments define flat storage and its appropriate use. Comments on the specific plan are important for the user to implement the plan successfully and include recommendations on vapor barrier, roofing, post size and spacing, and grain liners. Management comments include the need for clean grain, good air distribution, grain observation, temperature monitoring systems, fan operation, appropriate fan type, grain inspection, and other management procedures.

SUMMARY

An expert system (ASD) was developed for the design of aeration systems for farm-sized flat grain storages. The ASD requests information about the storage problem from a user and generates a custom design drawing, component specification list, and management recommendations. The knowledge base was derived from engineering handbooks,

extension publications, technical articles, and experts. The ASD represents the first attempt to consolidate aeration system design guidelines and procedures for flat grain storage into an expert system.

The ASD consists of interview, calculation, design drawing, and management recommendations components. The interview component uses illustrations to communicate concepts and terminology more clearly with users. The calculation component of the expert system was implemented with a separate program to size posts, estimate storage capacity, and lay out and specify aeration system components. The design drawing component displays and prints a floor plan of the custom aeration system. Management recommendations are printed for the user's reference in installing and managing the aeration system.

Alternative methods for determining the layout and length of ducts were incorporated into the ASD. A feature of ASD allows an expert to customize the component specifications and design guidelines. For aeration system design engineers, ASD offers the capability of rapidly designing an aeration system and changing design guidelines to study the effects upon the design. An aeration system design engineer can customize the component specifications to match equipment which is readily available and change design guidelines to match local preferences. Customized versions of the ASD can be distributed to county extension offices and sales offices of aeration component suppliers for use by staff to design aeration systems for clients. The aeration system design program is available from the IFAS Software Support office, University of Florida, 0162 IFAS, Gainesville, Florida 32611-0162.

REFERENCES

ASAE Standards, 34th ed. 1987. St. Joseph, MI: ASAE.

Brook, R.C. 1979. Aeration systems for dry grain. Agricultural Engineering Information Series bulletin AEIS-391, File No. 18.151. Michigan State University, E. Lansing.

Brook, R.C. and E.W. Harmsen. 1982. Aeration fan and duct selection for flat grain storage. User's Manual for TELCAL 2.2. Cooperative Extension Service, Michigan State University, E. Lansing.

Burrell, N.J. 1974. Aeration, Ch. 12. In Storage of Cereal Grains and Their Products. American Association of Cereal Chemists, St. Paul, MN.

Carroll, N.J., G.A. Peterson and D.G. Watson. 1987. Parametric computer aided drafting for agricultural engineering. ASAE Paper No. 87-3065. St. Joseph, MI: ASAE.

Cloud, H.A. and R.V. Morey. 1980. Fan and equipment selection for natural-air drying, dryeration, in storage cooling, and aeration systems. Agriculture Extension Service bulletin No. M-166. University of Minnesota, St. Paul.

Foster, G.H. and J. Tuite. 1986. Aeration and stored grain management, Ch. 5 In *Storage of Cereal Grains and Their Products*. American Association of Cereal Chemists, St. Paul, MN.

Holman, L.E., compiler. 1960. Aeration of grain in commercial storages. Marketing Research Report No. 178. Transportation and Facilities Research Division, Agricultural Marketing Service, USDA.

Irish, W.W., G.D. Wells, R.A. Parsons and G.R. Bodman. 1984. Pole and post buildings: Design and construction handbook. Cooperative Extension, Northeast Regional Agricultural Engineering Service.

MWPS. 1987. Grain drying, handling, and storage handbook, MWPS-13. Midwest Plan Service, Ames, IA.

Peterson, G.A., D.G. Watson, R.C. Brook and D.R. Kightlinger. 1988. INTPRO: A tool for developing interactive computer graphics program. In *Proc. of the 2nd International Conference on Computers in Agricultural Extension Programs*, 10-11 February, Lake Buena Vista, FL.

Peterson, G.A., D.G. Watson and R.C. Brook. 1988. INTPRO and RECPRO: Tools for software development. ASAE Paper No. 88-3029. St. Joseph, MI: ASAE.

Watson, D.G. 1987. Aeration system design for flat grain storages utilizing interactive computer graphics. Ph.D. diss., Dept. of Agricultural Engineering, Michigan State University, E. Lansing.

Watson, D.G., M.P. Andrews and R.C. Brook. 1988. Evaluating a computer program with a structured expert review process. *Applied Engineering in Agriculture* 4(4): 350-355.

Watson, D.G., G.A. Peterson and W.G. Bickert. 1986. Software system for developing interactive computer graphics applications. ASAE Paper No. 86-5027. St. Joseph, MI: ASAE.