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Spray evaporation losses from sprinkler irrigation systems

R.K. McLean, R. Sri Ranjan and G. Klassen. Can. Agric. Eng. 42:001-008

Minimising the loss of water from irrigation systems is important for achieving water and energy conservation. Water is lost during storage, conveyance and field application. In sprinkler irrigation systems, the loss that occurs in the field is the largest of the three. The above canopy spray evaporation loss (ACSEL) represents the portion of the water that is lost to the atmosphere during the time it travels from the sprinkler nozzle to the crop canopy. The electrical conductivity (EC) method was used to determine the ACSEL from different types of sprinkler irrigation systems calculated at increasing distances from the sprinkler nozzles. In this method, the change in solute concentration and consequent change in EC as the water droplets travel through the air was used to calculate the volume lost by evaporation. The travelling gun irrigation systems showed the largest variation in ACSEL. The ACSEL varied depending on whether the water droplets travelled into the wind or with the wind. Therefore, for measuring ACSEL, it is important to place the collectors on either side of the travelling gun. The wind direction in relation to the average travel direction of the gun also affected the uniformity of ACSEL. The centre pivot irrigation systems gave the most uniform ACSEL across the different nozzles. Therefore, for centre pivot systems, about four to six collectors per row is sufficient to determine ACSEL in the field with a precision of ± 0.5%.

Afin d'améliorer la conservation de l'eau et de l'énergie en irrigation, il est important de minimiser les pertes d'eau des systèmes. L'eau est perdue lors de l'entreposage, du transport et de l'application au champ. Pour les systèmes d'irrigation par aspersion, la perte d'eau au champ est la plus importante des trois. La perte d'eau par évaporation au-dessus du feuillage (ACSEL) représente la partie de l'eau qui est perdue dans l'atmosphère au moment où elle passe de la buse au feuillage. La méthode de la conductivité électrique (EC) fut utilisée pour déterminer l'ACSEL de différents types de systèmes d'irrigation par aspersion, à des distances croissantes des buses. Le volume d'eau perdu par évaporation fut calculé grâce à la mesure du changement de concentration de la solution, et donc du changement de conductivité électrique (EC), des gouttes qui se déplacent dans l'air. Les plus grandes variations d'ACSEL furent observées avec des systèmes d'irrigation à canon mobile. L'ACSEL variait selon que les gouttes se déplaçaient avec ou contre le vent. Il est donc important, lorsqu'on mesure l'ACSEL, de placer les récipients collecteurs de chaque côté du canon mobile. La direction du vent par rapport à la direction moyenne de déplacement du canon eut également un effet sur l'uniformité de l'ACSEL. Les valeurs d'ACSEL de systèmes d'irrigation à pivot central furent les plus uniformes. Quatre à six récipients collecteurs par rangée sont donc suffisants pour déterminer l'ACSEL d'un système d'irrigation à pivot central à une précision de ± 0.5%.

Comparison of energy inputs for inorganic fertilizer and manure based corn production

N.B. McLaughlin, A. Hiba, G.J. Wall and D.J. King. Can. Agric. Eng. 42:009-017

Energy inputs were calculated for grain corn production with data from field experiments utilizing inorganic fertilizer and liquid swine manure as sources of plant nutrients. The calculations utilized energy coefficients taken from the literature and actual application rates of the various input products including seed corn, starter fertilizer and regular inorganic fertilizer, herbicides, fuel for field operations, and grain drying. The results showed that grain corn could be produced successfully by substituting manure for inorganic fertilizer. The energy savings in the manured treatments resulted largely from eliminating the energy in fertilizer manufacture and ranged from 31 to 34% of the energy input for inorganic fertilizer based grain corn production. Published agricultural statistics were used to extrapolate the results to the entire Mixedwood Plains Ecozone which covers the lower Great Lakes and St. Lawrence River Valley regions of Ontario and Quebec. An estimated upper bound of 4.6 PJ (1 petajoule = 10^{15} joules) of energy could be saved annually by substituting livestock manure for inorganic fertilizer in the production of the entire acreage of grain corn grown in the ecozone. This estimate is based on the assumptions of availability of sufficient manure, and no credits being given for manure presently being used. Spatial analysis identified South Western Ontario and the Richileau - St. Hyacinthe region of Quebec as the areas where the potential energy savings would be greatest.

La consommation énergétique requise pour la production du maïs grain a été calculée avec des données provenant de champs expérimentaux où des fertilisants inorganiques et du lisier de porc étaient utilisés. Pour les calculs, on a utilisé des coefficients énergétiques tirés de la littérature, et les taux d'application réels d'intrants pour le semis, le démarreur et les fertilisants organiques réguliers, les herbicides, le carburant pour les opérations dans les champs et pour le séchage du grain. Les résultats ont montré qu'il était possible de produire avec succès du maïs grain en substituant le lisier de porc aux fertilisants organiques. Les économies d'énergie résultant de l'utilisation du lisier pouvaient être, dans une large mesure, attribuées à l'élimination de l'énergie utilisée pour produire les fertilisants inorganiques, et représentaient de 31 à 34% de la consommation d'énergie nécessaire à la production de maïs grain avec des fertilisants inorganiques. En utilisant les statistiques agricoles publiées, il fut possible d'extrapoler les résultats à toute la zone écologique de la forêt mixte qui couvre la partie inférieure des Grands-Lacs et la vallée du St-Laurent en Ontario et au Québec. On a estimé qu'une quantité maximale de 4.6 PJ (1 petajoule = 10^{15} joules) pourrait être économisée annuellement si on substituait du lisier de porc aux engrais inorganiques sur toute la superficie en maïs de la zone écologique. Cette évaluation repose sur l'hypothèse qu'il y a du lisier en quantité suffisante, et qu'on ne tient pas compte du lisier actuellement utilisé. Avec cette analyse spatiale, on a identifié que le potentiel d'économie d'énergie serait le plus grand dans le sud-ouest de l'Ontario et la région Richelieu-St-Hyacinthe au Québec.

Performance of wheel and track running gear on liquid manure spreaders

R.A. McBride, N.B. McLaughlin and D.W. Veenhof. Can. Agric. Eng. 42:019-025

A field experiment was conducted to characterize soil-vehicle interactions and to measure tractor power/fuel requirements when hauling a fully loaded tank spreader (18 m^3) fitted with rubber tracks (2721x635), high flotation tires (28L26) or conventional truck tires (445/65R22.5). A second objective was to apply an existing soil compaction model to the data from this field trial and to determine if its estimates of wheel rut depth were reasonable. The experiment was carried out in late autumn on a harvested soybean field (silt loam soil) located in southwestern Ontario. Fuel consumption and drawbar draft were measured during the traffic treatments with an instrumented tractor, and selected soil properties were measured afterwards. An analytical-type soil compaction model was used to estimate the wheel rut depth for the two pneumatic tire treatments. The type of running gear had a highly significant effect on both drawbar draft and fuel consumption ($p < 0.001$), with the tracks having the highest values (mean 24.6 kN and 21.5 L/h, respectively) and the flotation tires having the lowest (mean 13.9 kN and 16.9 L/h, respectively). The truck tires left ruts with a mean depth of 42.3 mm, while the flotation tires left cleat impressions that were barely discernable. A pedotransfer function was used to estimate the preconsolidation stress (26 kPa) and compression index (0.173) of the plow layer soil and, with these and other input data, the soil compaction model estimated rut depths that were quite comparable to those observed. The only ruts produced by the tracks were those of the track grousers (about 48 mm deep), but extensive soil shearing was evident. The tracks and truck tires produced significantly higher ($p < 0.05$) measured dry bulk densities at a depth of 150 mm when compared to those induced by the flotation tires. Soil cone penetrometer measurements were not as conclusive in distinguishing the impact of the running gear treatments on soil structural conditions. In general, however, flotation tires appeared to be the preferred running gear option with respect to several key parameters (fuel consumption, drawbar draft, wheel rut depth, dry bulk density) under these particular soil and loading conditions. **Keywords***:* high axle load traffic, soil-vehicle interactions, wheel rutting, soil compaction model, pedotransfer function.

Une expérience en champs a été effectué pour évaluer les interactions sol-véhicule et mesurer les exigences puissance/carburant du tracteur lorsque tirant un épandeur plein (18 m^3) et équipé de chenilles (2721x635), de pneus à grande flottation (28L26) ou de pneus de camion (445/65R22.5). Un deuxième objectif visait à employer un modèle existant de compaction du sol en utilisant les données des tests au champs, et de determiner sa capacité prédictive (profondeur de l'ornière). L'expérience a été menée en fin d'automne dans un champs de soya déjà récolté (loam limoneux) au sud-ouest de l'Ontario. La consommation en carburant et l'effort de traction ont été mesurés durant les déplacements avec un tracteur spécialement équipé, et certaines propriétés du sol ont été mesuré par la suite. Un modèle analytique de compaction du sol a été utilisé pour estimer la profondeur des ornières des deux types de pneumatiques. Le système mécanique de transport a eu un effet significatif sur l'effort de traction et sur la consommation en carburant ($p<0,001$), les chenilles ayant les plus hautes valeurs (moyennes de 24,6 kN et 21,5 L/h, respectivement) et les pneus de grande flottation les plus faibles (moyennes de 13,9 kN et 16.9 L/h, respectivement). Les pneus de camions ont laissé une profondeur moyenne d'ornières de 42,3 mm, pendant que les pneus de flottation ont laissé des traces difficilement perceptibles. Une fonction de pédotransfert fut utilisée pour estimer la contrainte de préconsolidation (26 kPa) et l'index de compression (0,173) pour la couche arable, qui, combinées à d'autres données dans un modèle de compaction du sol, ont estimé des profondeurs d'ornières comparables à celles observées. Les seules traces produites par les chenilles étaient celles des parties en relief (approximativement 48 mm de profond), mais un important cisaillement du sol était observé. Les chenilles et les pneus de camion ont produit une mesure de densité apparente à une profondeur de 150 mm significativement plus haute ($p<0,05$) que les pneus de flottation. Les mesures de la résistance à la pénétration du sol se sont révélées incapable de distinguer les impacts des traitements sur la structure du sol. Généralement, les pneus à grande flottation ont été l'option préfèrée en ce qui concerne plusieurs facteurs importants (consommation en carburant, effort de traction, ornières de roue, densité apparente) sous ces conditions de sol et de trafic. **Mots-clés***:* transport à charge lourde, interactions sol-véhicule, ornières de roue, modèle de compaction du sol, fonction de pédotransfert

Grain conditioning for dehulling of canola

J.A. Ikebudu, S. Sokhansanj, R.W. Tyler, B.J. Milne and N.S. Thakor. Can. Agric. Eng. 42:027-032

Several conditioning treatments to promote dehulling of canola grain (*Brassica napus* L.) were investigated. The tested treatment sequences were: (1) moistening, heating; (2) heating, moistening; and (3) heating. Moistening was done by spraying a predetermined quantity of water on the grain. A thin layer dryer and a fluidized bed dryer were used to heat/dry the grain. Following each treatment, the samples were dehulled in an abrasive dehuller. The dehulled samples were fractionated on an aspirator. A dehulling index was evaluated considering four mass fractions of cotyledon, hulls, undehulled grains, and fines. The maximum dehulling index of 0.88 (dehulling index ranges from –1 to +1) was achieved by moistening the grain to about 15% moisture content (wet basis) for 10 min followed by heating at 70-75˚C for 5 min. A similar dehulling index was achieved by heating the grain at 120˚C for 5 min without moistening. The control grain had a dehulling index of -0.47. **Keywords**: canola, dehulling, conditioning, splitting, oilgrain, rapeseed. abrasive, fractionation, dry separation.

Plusieurs traitements de conditionnement facilitant le dépelliculage des grains de canola (*Brassica napus* L.) furent étudiés. Les séries de traitements examinées étaient les suivantes : (1) humidification, chauffage; (2) chauffage, humidification; et (3) chauffage. L'humidification des grains fut faite en les vaporisant d'une quantité d'eau prédertiminée. Un appareil de séchage sur couche mince et un appareil de séchage par lits fluidisés furent utilisés pour chauffer/sécher les grains. A la suite de chaque série de traitements, les échantillons furent dépelliculés avec une machine abrasive à dépelliculer. Les échantillons dépelliculés furent séparés avec un aspirateur. Un indice de dépelliculage fut établi en fonction des masses de quatre fractions obtenues lors de la séparation : cotylédons, pellicules des grains, grains avec pellicule et fractions fines. L'indice maximal de dépelliculage de 0.88 (indice variant de –1 à 1) fut obtenu en humidifiant le grain durant 10 min jusqu'à une teneur en humidité de 15 % (base humide), et en le chauffant ensuite à 70-75 °C pendant 5 min. On obtint une valeur d'indice comparable en chauffant le grain à 120°C pendant 5 min, sans l' humidifier. L'échantillon de contrôle avait un indice de dépelliculage de –0.47. **Mots-clés** : canola, dépelliculage, conditionnement, séparation, oléagineux, colza, abrasif, fractionnement, séparation à sec.

Mechanical compaction of flour: the effect of storage temperature on dough rheological properties

S. Cenkowski, J.E. Dexter and M.G. Scanlon. Can. Agric. Eng. 42:033-041

The effects of storage temperature, storage time, and compaction of compressed flour on functional and rheological properties of dough were investigated for flour milled from No. 1 Canadian Western Red Spring wheat. Untreated (loose) flour and flour that had been mechanically compacted to a 55% volume reduction were stored for one year at 20, 30, and 40°C. An imitative rheological test (capillary rheometry) indicated that compaction of 75% extraction rate flour had a marked effect on the magnitude of the flow behaviour index (n). This effect was not observed in 83% extraction rate flour. Storage time had a substantial effect on all samples, increasing the n values by 5 to 15%. A similar effect was observed for consistency coefficient. Alveograph and farinograph results indicated that the main factor affecting the oxidation of compacted and loose flours during storage was the storage temperature. Compaction of flour appeared to have a slight mitigating effect on changes to alveograph curves during storage. Storage of flour up to 30°C caused changes in dough rheological parameters, indicating a dough strengthening effect. Storage of flour at 40°C resulted in tight inextensible dough that would be difficult to process in bakeries. Capillary extrusion tests confirmed that the flow behaviour index was noticeably affected by storage temperature.

Les effets de la température d'entreposage, de la durée de l'entreposage et de la compaction de la farine sur les propriétés fonctionnelles et rhéologiques de la pâte furent examinés. Les expériences furent faites avec de la farine obtenue par la mouture de blé roux de printemps catégorie no. 1 de l'ouest canadien. De la farine non-traitée (non comprimée) et de la farine comprimée mécaniquement jusqu'à 55 % de réduction de volume furent entreposées durant un an à 20, 30 et 40°C. Un test de simulation des comportements rhéologiques (rhéométrie capillaire) montra que la compression de farine ayant un taux d'extraction de 75 % avait un effet important sur l'indice d'écoulement (n). Cet effet ne fut pas observé avec de la farine ayant un taux d'extraction de 83 %. La durée de l'entreposage eut un effet substantiel sur tous les échantillons, provoquant une augmentation de 5 à 15 % des valeurs de n. On observa un effet semblable sur le coefficient de consistance. Les résultats des alvéographes et des farinographes montrèrent que la température d'entreposage était le facteur qui affectait le plus l'oxydation des farines non-comprimées et comprimées. La compaction de la farine semble atténuer les changements observés sur les alvéographes lors de l'entreposage. L'entreposage de la farine à des températures atteignant 30°C provoqua des changements dans les paramètres rhéologiques de la pâte qui indiquaient un raffermissement. La farine entreposée à 40°C produisit une pâte serrée peu extensible et qui serait difficile à travailler en boulangerie. Les tests d'extrusion capillaire confirmèrent que l'indice d'écoulement était sensiblement affecté par la température d'entreposage.

Dehydration dynamics of potatoes in superheated steam and hot air

Z.W. Tang and S. Cenkowski. Can. Agric. Eng. 42:043-049

Superheated-steam at atmospheric pressure is an alternative drying medium for dehydrating materials insensitive to temperature equal to or above 100°C. This research compared the dehydration characteristics, temperature histories, drying rates, and overall moisture diffusivities of cylindrical potato samples exposed to superheated steam and hot air at 125, 145, and 165°C. A small amount of moisture (0.18 to 0.47 kg/kg db, dry basis) dependent on the steam temperature was gained from steam condensation on the sample surface during the warm-up period from the superheated-steam. The temperature of the drying medium had a greater effect on the drying rate, overall moisture diffusivity, and consequently dehydration time for the superheated-steam dehydration than for the hot-air dehydration. Increasing the temperature from 125 to 165°C decreased the dehydration time by 60 and 24% for the superheated-steam and hot-air dehydration, respectively. A constant-rate drying period was only observed with superheated steam at 125 and 145°C. There existed an inversion temperature point between 145 to 165°C for the first dehydration stage above 2.6 kg/kg db and between 125 and 145°C for the last dehydration stage below 2.6 kg/kg db.

La vapeur surchauffée à la pression atmosphérique est utilisée comme milieu de séchage alternatif pour déshydrater des matières insensibles à des températures égales ou supérieures à 100°C. Ces recherches comparèrent les caractéristiques de déshydratation, les variations de température, les taux de séchage et la diffusion globale de l'humidité d'échantillons cylindriques de pomme de terre exposés à de la vapeur surchauffée et à de l'air chaud à 125, 145, et 165°C. Lors du procédé à la vapeur surchauffée, et selon la température de la vapeur, un léger gain d'humidité (0.18 à 0.47 kg/kg bs, base sèche) se produisit à cause de la condensation de la vapeur à la surface de l'échantillon durant la période de réchauffement. La température du milieu de séchage eut un effet plus important sur le taux de séchage, la diffusion globale de l'humidité, et en conséquence sur le temps de déshydratation, dans le procédé de déshydratation à la vapeur surchauffée que dans le procédé à l'air chaud. Lorsque la température passa de 125 à 165°C, le temps de déshydratation diminua de 60 % pour la déshydratation à la vapeur surchauffée et de 24% pour le procédé à l'air chaud. Une période de séchage à taux constant fut observée avec la vapeur surchauffée à 125 et 145°C. Il y eut un point d'inversion de la température entre 145 et 165°C pour le premier stade de déshydratation au-dessus 2.6 kg/kg bs, et entre 125 et 145°C pour le dernier stade de déshydratation sous 2.6 kg/kg bs.

Water activity of freeze dried mushrooms and berries

S. Khalloufi, J. Giasson and C. Ratti. Can. Agric. Eng. 42:051-056

Sorption isotherms at 4, 13, and 27°C were obtained for two types of berries (strawberries and blueberries) and three types of commercial and wild mushrooms (Shiitake *Lentinus edodes*, Enoki *Flammulina velutipes* and Morel *Morchella esculenta*). The products had been freeze-dried for 72 h and equilibrated over saturated salt solutions in a range of relative humidity from 11 to 87%. The equilibrium moisture content was obtained when there was no appreciable change in sample weight. The sorption of powdered and whole pieces of mushrooms was studied in order to evaluate possible effects of particle size on sorption characteristics. Two equilibrium models, GAB and one previously developed by one of the authors, were tested against the experimental data in order to determine the most appropriate mathematical representation. The constants required for each model were determined by non-linear regression analysis.
Keywords: water activity, freeze-dried products, sorption isotherms, modelling.

Des isothermes de sorption ont été obtenues pour deux variétés des petits fruits (fraises et bleuets) et pour trois types de champignons comestibles (Shiitake *Lentinus edodes*, Enoki *Flammulina velutipes* et Morille *Morchella esculenta*). Les expériences se sont déroulées à 4, 13 et 27˚C. Après avoir été lyophilisés durant 72 h, les échantillons sont mis en équilibre avec des solutions saturées entre 11 et 87% d’humidité relative. L‘équilibre était observé lorsqu’il n’y avait plus de changement appréciable dans le poids de l‘échantillon. Le comportement des champignons en poudre et des champignons en entier a été étudié afin de voir l’effet de la taille de particule sur les caractéristiques d’adsorption. Deux modèles, celui de GAB et un autre développé par un des auteurs, ont été testés afin de trouver la représentation mathématique la plus appropriée pour les résultats expérimentaux. Les constantes intervenantes dans chaque modèle ont été déterminées par l’analyse de la régression non-linéaire.

Characteristics of hydrogen sulphide concentrations in mechanically ventilated swine buildings

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Ni, J.-Q., Heber, A.J., Diehl, C.A., Lim, T.T., Duggirala, R.K. and Haymore, B.L. 2002. **Characteristics of hydrogen sulphide concentrations in mechanically ventilated swine buildings**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **44**:6.11-6.19. Hydrogen sulphide (H_2S) concentrations in two mechanically ventilated swine buildings (3B and 4B) were continuously measured with fluorescence-based analyzers for six months. Air containing H_2S was automatically sampled 24 and 16 times daily from three locations: pit headspaces, pit ventilation fans, and wall ventilation fans. A total of 219 d of complete and validated data were selected to study temporal and spatial variations of H_2S concentrations in the buildings. Average daily mean H_2S concentrations were 180±16 (mean ± 2 standard errors of the mean) and 232±39 ppb in buildings 3B and 4B, respectively. Seasonal variations occurred as daily mean concentrations ranged from 18 to 1107 ppb. Expected saddle-shaped seasonal patterns from April to September, inversely correlated to the ventilation pattern, were observed. Four distinct diurnal patterns of H_2S concentrations were also identified. The maximum and minimum concentrations during fair weather occurred between 3:00-6:00 and 12:00-18:00, respectively. Spatial concentration variations were also observed as the daily mean concentration differences between any two sampling locations ranged from 20±6 to 132±17 ppb. **Keywords**: air quality, air pollution, environment, pig house, ventilation rate, temperature

Concentrations de sulfure d'hydrogène (H_2S) dans deux grandes porcheries (3B et 4B) ventilées mécaniquement ont été mesurées continuellement pendant six mois avec deux appareils fluorescents. L'air, contenant H_2S, a été testé pendant 24 et 16 intervalles de temps par jour dans trois différentes locations: Au-dessus du plancher, devant les éventails des cheminées et devant les éventails du mur. Un total de 219 jours de données validées a été choisi pour étudier les variations temporelles et spatiales des concentrations de H_2S dans les porcheries. Les moyennes par jour des concentrations de H_2S pendant toute l'expérience dans la porcherie étaient de 180±16 (moyenne ± 2 erreurs critères) et 232±39 ppb pour 3B et 4B, respectivement. Changements saisonniers de concentrations prenaient place lorsque les concentrations moyennes dans les porcheries se rangeaient entre 18 et 1107 ppb. Un modèle d'une forme de la selle des concentrations de H_2S, correspondant inversement aux débits des ventilations, était remarqué de l'avril au septembre. Quatre modèles de variation diurne des concentrations de H_2S ont été identifié. Les concentrations pendant les beaux jours atteignaient le maximum entre 3:00-6:00 et le minimum entre 12:00-18:00. Variations spatiales des concentrations ont été remarquées aussi puisque la moyenne par jour des différences absolues entre les concentrations dans n'importe quelles deux locations se rangeaient entre 20±6 et 132±17 ppb.

Mention of specific equipment is for the benefit of readers and does not infer endorsement or preferential treatment of the product names by the authors.

INTRODUCTION

Hydrogen sulphide (H_2S) is produced by anaerobic fermentation of manure, and high concentrations are toxic to humans and animals. A H_2S concentration of 50 ppm can cause dizziness, irritation of the respiratory tract, nausea, and headache. Death from respiratory paralysis can occur with little or no warning when exposed to concentrations exceeding 1000 ppm (Field 1980). It has been responsible for many animal as well as human deaths in animal facilities (Field 1980; Anonymous 1996).

The H_2S concentration is usually very low in animal houses compared with other gases like carbon dioxide (CO_2) and ammonia (NH_3) in swine buildings. It was measured at 90 ppb in a normally ventilated confinement building and 280 ppb after the ventilation was shut off for six hours (Muehling 1970). The H_2S concentration was 166 ppb in two naturally ventilated swine houses during a 63-day study in Indiana (Heber et al. 1997).

Although there have been reports about H_2S concentrations in swine houses, most studies were relatively short in duration and consisted of single spot measurements. However, the generation of H_2S in animal houses is affected by manure production and storage, temperature, manure disturbance, air exchange rate in the manure storage head space, and other factors that continuously change. The clearance of gas from inside the houses is controlled by ventilation rate, which is usually designed to regulate room temperature. Seasonal and diurnal ambient temperatures thus indirectly affect the production and dilution of H_2S in the houses, therefore causing temporal variations of H_2S concentrations. Anaerobic decomposition should decrease with colder slurry temperature and therefore decrease H_2S production; however, lower airflow in cold weather tends to increase concentrations. An animal house is also an imperfectly mixed ventilation space, which causes gas concentration gradients. Better understanding of temporal and spatial variations of H_2S concentration in swine houses is important for creating a healthier environment for animals and workers.

The objective of this study was to evaluate the characteristics of H_2S concentration measured in two mechanically ventilated swine buildings over six months. The specific objectives were:

1. To evaluate seasonal and diurnal variations of H_2S concentrations and the factors that may have influenced them, and
2. To evaluate spatial variations of H_2S concentrations.

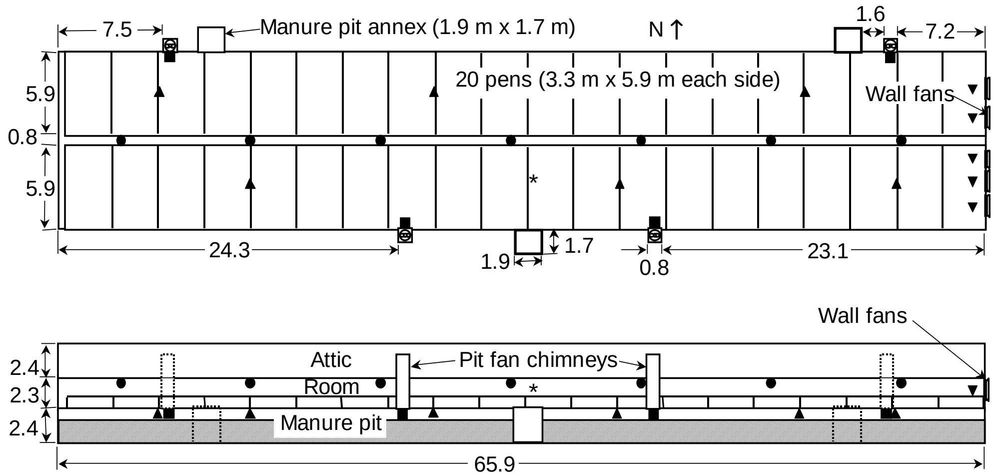

Fig. 1. Floor plan (top) and side view (bottom) of the building with instrument and sampling locations (pressure *, temperature !, and air sampling locations for SLG 1 ▲, SLG 2 #, and SLG 3 ▼). All dimensions in meters.

EXPERIMENTAL PROCEDURE

Experimental building

The data presented in this paper were collected from two, mechanically ventilated, swine finishing buildings of standard size (nominal 1000-pig capacity) involved as untreated controls in a field test of a manure additive conducted in 1997 (Heber et al. 2000). The two buildings (designated "3B" and "4B") were located on a farm in Illinois.

Each building was 12.6 m x 65.9 m and had a 2.4 m deep pit under a fully slatted floor with a pit surface area of 799 m^2 (Fig. 1). There were four pit ventilation exhaust fans and five wall ventilation exhaust fans in each building. The 457-mm diameter variable-speed pit fans, installed in vertical chimneys, operated continuously. The buildings were tunnel-ventilated during hot weather. One, 914-mm diameter and four, 1219-mm diameter exhaust fans were located on the east wall of each building. Further details of the buildings and test equipment were presented by Heber et al. (2001).

Air quality measurements

Air quality measurements began on March 6 and ended on September 25. Only days with 24 h of validated data were selected for this analysis of H_2S concentrations. Data collection occurred between March 18 and September 24 at 3B (124 d) and between April 5 and September 25 at 4B (95 d).

Hydrogen sulphide was measured with a pulsed-fluorescence sulphur dioxide (SO_2) analyser (Model 45, TEI, Inc., Mansfield, MA) after being converted to SO_2 with a H_2S converter (Model 340, TEI, Inc.). One instrument set (converter and analyser) was used with each building. The H_2S measurement system was calibrated with certified gas on June 26; July 3, 11, and 21; August 8 and 27; and September 5 and 17. Hydrogen sulfide concentration was measured in air streams continuously drawn from the following sampling location groups (SLGs): 1) pit headspace (six sampling points), 2) pit fans (four sampling points), and 3) wall fans (five sampling points). Multiple sampling points in each group were connected in parallel to the air sampling system (Fig. 1). Four sampling points located 0.5 m upstream of the inlets to the four 1219-mm diameter wall fans were controlled individually with computer-operated solenoids (Heber et al. 2001). They were open only when corresponding fans operated. The air sampling tube for the 914-mm wall fan was always open.

Only SLGs 1 and 2 were active until SLG 3 was installed on June 4 and July 16 in 3B and 4B, respectively. Until SLG 3 was installed, gas concentrations during each 60-min sampling cycle were measured continuously during a 15-min sampling period at each SLG before pneumatically switching to another SLG. Blocks of data collected at 1.0 Hz were averaged and stored every 20 s. The other 50% of each sampling cycle (30 min) was allocated for measuring gas concentrations in an adjacent building treated with a manure additive (Heber et al. 2000). Thus 24 period means (PMs) of gas concentrations at each SLG were obtained daily. When SLG 3 was added, the number of PMs decreased to 16 per day with 90-min sampling cycles. The number of PMs increased again to 24 per day on August 14 when the sampling period was reduced from 15 to 10 min. The first 3 min of H_2S concentration data during 15- and 10-min sampling periods were ignored to allow gas analyzers to equilibrate. The 12 or 7 min of useful gas concentration data obtained in each sampling period were averaged to calculate period means. The cycle mean for a given location was represented by the period mean.

Pigs were weighed twice, before entering the building and at the market when sold. The average mass of pigs before the group reached market size was calculated based on beginning mass and residence time in the building and an average growth rate of 0.75 kg/d (Ni et al. 2000). Mean pig masses measured at market also were used to adjust calculated pig mass during the growth cycle. The study included two partial pig growth cycles in each building.

Building ventilation rate was the sum of the total wall fan airflow rate and the total pit fan airflow rate. Wall fan airflow rates were calculated using fan curves determined by independent tests and measured differential static pressure between room and ambient air.

In building 4B, a full-size impeller anemometer (FanCom Model FMS 50, Techmark, Lansing, MI) was installed inside each pit fan chimney below the ventilation fan. The airflow rate produced by the pit fans was the sum of airflows measured by the four anemometers. Anemometers were not used in 3B, thus the pit fan airflows were estimated based on fan control voltage and were verified with a manual traverse of chimney air velocities with a hot-wire anemometer. The four pit fans were controlled in parallel by one fan speed controller. An

Table 1. Quantity of data used in this study.

	March	April	May	June	July	Aug	Sept	Total
Days								
Total	6	23	46	38	30	49	27	219
3B	6	9	21	20	24	28	16	124
4B	0	14	25	18	6*	21	11	95
Data subsets								
Total	144	552	1104	616	480	1000	648	4544
3B	144	216	504	328	384	568	384	2528
4B	0	336	600	288	96	432	264	2016

* A lightning strike occurred in July causing a loss in data.

airflow/voltage relationship was determined from other identical buildings at the farm that were equipped with anemometers on the pit fans. However, the pit fans were operated at full speed most of the time during this study.

Air temperatures were measured with semiconductor sensors with stainless steel probes (Model AD592CN, Analog Devices, Norwood, MA). Room temperatures measured 2 m above the floor at seven locations equally spaced along the centre of each building length, and ambient temperature were used in this paper. Temperature sensors were calibrated with a constant temperature bath before the test began.

Some definitions of mean concentrations were adopted to study the H_2S over different durations and at different locations (SLGs 1 to 3). The building concentration is defined as the mean of the concentrations at SLGs 1, 2, and 3; however, it was represented by SLGs 1 and 2 prior to SLG 3 installation. The period mean (PM) is the average concentration of the extracted 7 or 12 min of data taken every 20 s. The average period mean (APM) is the average of PM concentrations of the same period number, e.g. 1 to 16 or 1 to 24, over a selected number of days. The daily mean (DM) concentration is the average of PM concentrations over one day. The average daily mean (ADM) is the overall average of DM concentrations.

The investigation of H_2S concentration characteristics in each building was conducted with the following steps:

1. Raw data from field tests were processed to obtain period means of measured variables. Daily files with either 24 or 16 periods were generated. Pig inventory and average pig mass were incorporated into relevant files.
2. Twelve graphs of temperature, ventilation rate, H_2S concentration, etc. were printed for each day.
3. Complete days (24 h of valid data) were selected. Other data were not considered for this paper.
4. Daily means of H_2S concentrations and other variables were calculated to evaluate seasonal variations.
5. Daily graphs of PMs were visually classified according to diurnal patterns of ambient temperature, H_2S concentration, and building ventilation rate.
6. Data were processed by class and analysed statistically for diurnal variations, with separate analyses for 24 and 16 periods per day.
7. Data were further processed to obtain DM concentrations, ADM concentrations and other statistics.

RESULTS and DISCUSSION

A total of 4554 sampling periods or data subsets were selected among 219 complete days, of which 57% were from 3B (Table 1). Although lightning damage caused a 29-d loss of data in 4B beginning June 25, this study lasted much longer and had more frequent sampling than prior studies. Avery et al. (1975) evaluated H_2S with 80 spot measurements using a wet chemistry method. Using the same fluorescence technique described earlier, Heber et al. (1997) collected about 1500 similar data subsets in two naturally ventilated swine finishing buildings with undisturbed deep pits for 63 d in the winter. About 1700 data subsets from 3B collected between June and September were evaluated by Ni et al. (2002) who reported average daily mean H_2S concentration of 173 ppb and an average daily mean emission rate of 578 g/d.

Table 2. Average daily mean (ADM), daily mean (DM), and period mean (PM) hydrogen sulphide concentrations.

Location	Number of days	H_2S concentration (ppb)				
		ADM±2SE	DM Min*	DM Max*	PM Min*	PM Max*
Building 3B						
SLG 1	124	154±16	18	563	2	1098
SLG 2	124	213±18	14	590	3	1256
SLG 3	87	167±21	18	495	2	1624
Average	124	180±16	18	536	3	919
Building 4B						
SLG 1	95	191±36	24	1132	1	2756
SLG 2	95	255±41	29	1082	2	1824
SLG 3	38	378±51	182	731	110	2211
Average	95	232±39	28	1107	1	1572

*The minimum and maximum concentrations at different sampling locations and in the buildings did not necessarily occur during the same period or the same day.

Overview of concentrations

The ADM building H_2S concentrations of 180±16 ppb (mean±2SE) and 232±39 ppb in 3B and 4B, respectively (Table 2), were not significantly different (P>0.05). These mean concentrations were similar to the 166 ppb reported in

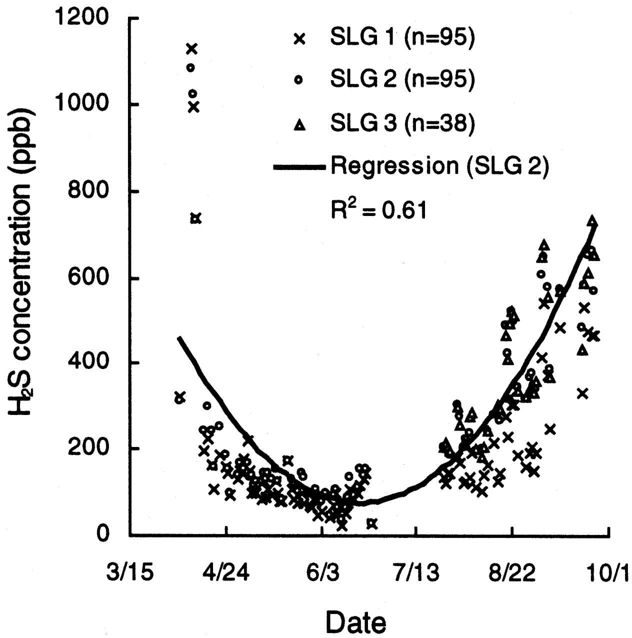

Fig. 2. Daily mean hydrogen sulphide concentrations at three sampling locations in building 3B.

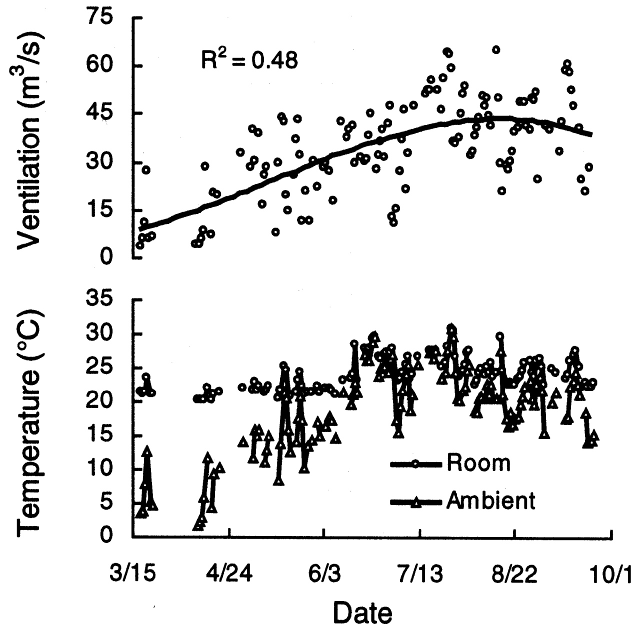

Fig. 4. Daily mean building ventilation rates and temperatures in building 3B.

the winter study conducted by Heber et al. (1997) using the same analytical method. The maximum PM H_2S concentration was 1624 ppb, as compared with the 8-h safety threshold of 10,000 ppb (OSHA 1999).

The DM concentrations ranged from 14 to 590 ppb at SLG 2 of 3B and from 24 to 1132 ppb at SLG 1 of 4B. The minimum PM concentrations were nearly 0 ppb at all SLGs in both buildings, except for the 110 ppb minimum at SLG 3 in 4B, perhaps due to a smaller number of measurements at that location. The maximum PM concentrations were 1624 ppb at SLG 3 of 3B and 2756 ppb at SLG 1 of 4B, but these peaks could not be related to specific activities in the buildings. Larger short-term variations of H_2S concentrations were evidenced by the spreads between minimum and maximum period means as compared with daily means (Table 2). The 3-h sampling periods used by Avery et al. (1975) in six swine units in Michigan resulted in a similar range of 120 to 2174 ppb.

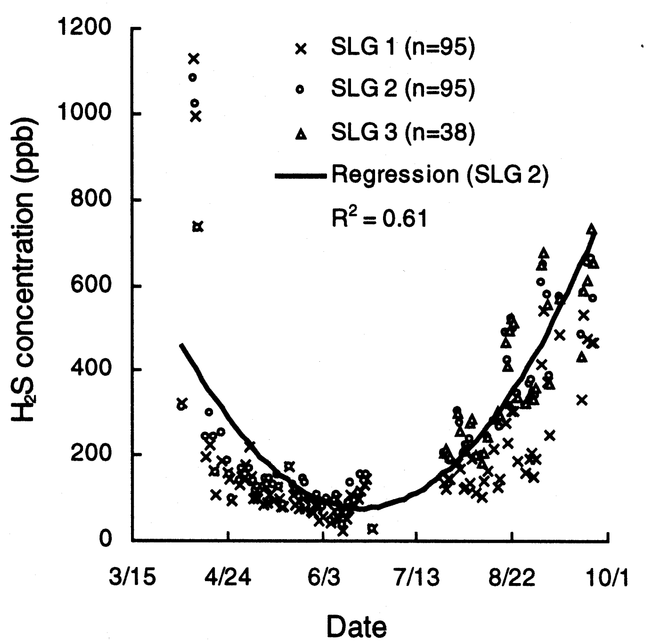

Fig. 3. Daily mean hydrogen sulphide concentrations at three sampling locations in building 4B.

Seasonal variations

Plots of DM concentrations at each SLG in both buildings are shown in Figs. 2 and 3. Relatively high mean DM concentrations occurred in late June and early July, especially at SLGs 1 and 2. Since manure was not disturbed, these high concentrations were apparently related to relatively low mean ventilation rates (Figs. 4 and 5) that were similar to mean ventilation rates in April. This occurred due to unseasonably low ambient temperatures (Figs. 4 and 5) combined with the presence of small pigs (Figs. 6 and 7).

Building ventilation diluted H_2S concentrations in the pit headspace and pit fan exhaust air resulting in correlation coefficients ($P<0.05$) between –0.37 and –0.69 (Table 3). It also had a direct impact on seasonal variations of H_2S concentration. The seasonal concentration variation was most evident in 4B, where part of the data in late June and early July was lost (Fig. 3). The seasonal concentration pattern was saddle shaped, with the lowest concentrations occurring during the first half of June and the highest during April and September. This pattern was inversely correlated (Table 3) to building ventilation rate and ambient temperature (Figs. 4 and 5). The highest DM H_2S concentrations in 4B were observed during April 10-12 when DM building ventilation rates were the lowest and pigs were

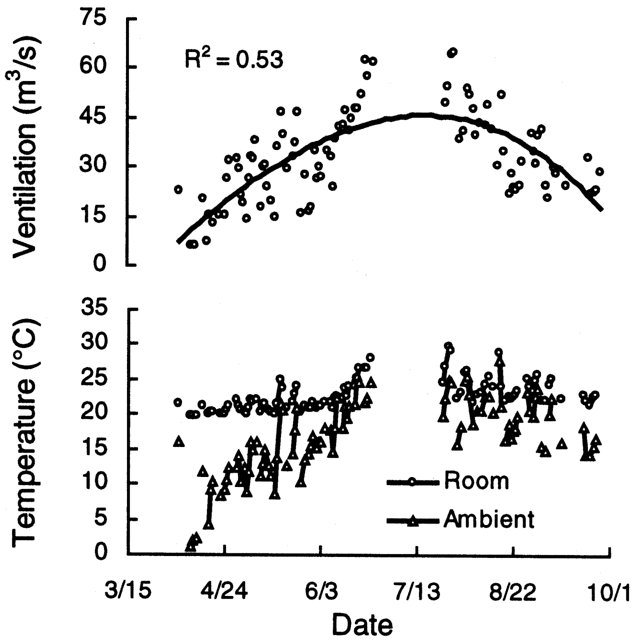

Fig. 5. Daily mean building ventilation rates and temperatures in building 4B.

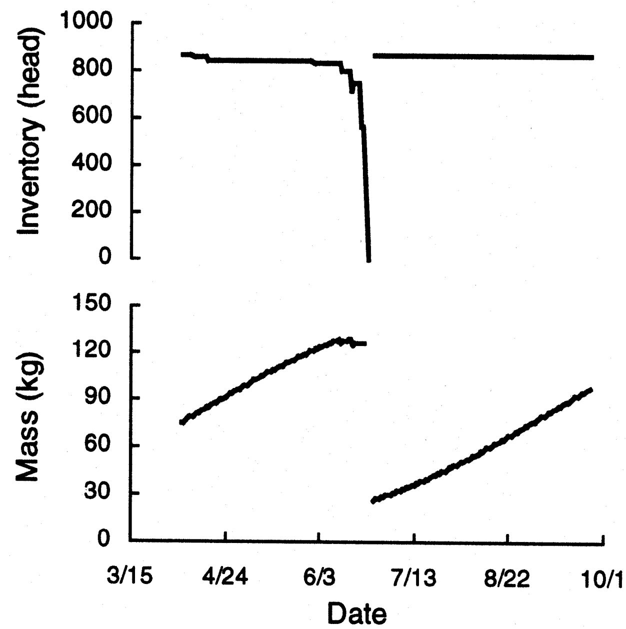

Fig. 7. Pig inventory and average pig mass in building 4B.

around 80 kg. High concentrations with small pigs and relatively cool temperatures at the beginning of the growth cycle were observed in 3B but lightning-induced data loss prevented similar observations in 4B with the same conditions.

Except for the very end of growth cycles, pig inventories decreased only slightly while mean pig mass steadily increased (Figs. 6 and 7). Fresh manure production is directly proportional to total pig mass, but gas concentration was apparently not correlated ($P<0.05$) to total pig mass (Table 3). The relatively

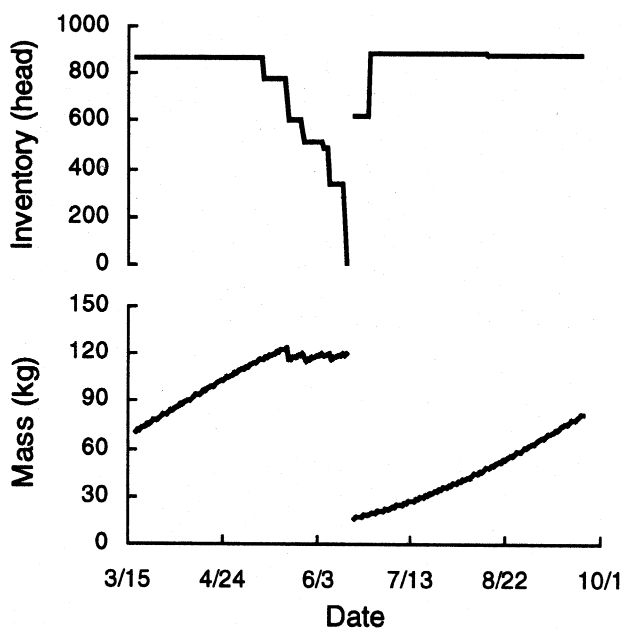

Fig. 6. Pig inventory and average pig mass in building 3B.

high positive correlation coefficients ($P<0.05$) between H_2S concentration and pig inventory in 4B were largely due to the coincidence of decreasing pig inventory and increasing ambient temperature during the first growth cycle and lack of data at the beginning of the second cycle.

Diurnal variations

Four distinct diurnal patterns of H_2S concentration were identified in this study. Each pattern and corresponding patterns of ventilation rate and temperature are given in Figs. 8 to 15. Patterns 1 to 3 were observed in 92% of the data (Table 4) and were characterized by diurnal variation that correlated to ambient temperature and building ventilation ($P<0.05$). Pattern 4 was observed in 4B between April and June and was unique in that concentrations were directly proportional to ventilation rate.

Pattern 1 was characterised by quasi-sinusoidal diurnal variation (Fig. 8). It occurred 44% of the time and showed an obvious change in H_2S concentration with time of day. The maximum and minimum concentrations occurred between 3:00 and 6:00 and between 12:00 and 18:00, respectively. The highest APM concentration was 860 ppb at 6:00 for SLG 3 in 4B, and the lowest was 73 ppb at 12:00 for SLG 3 in 3B. The greatest difference in APM concentration was observed at the wall fans in 3B for the 16-period sampling mode with 73 ppb at 12:00 as compared with 360 ppb at 6:00, a five-fold increase.

Pattern 1 occurred mostly during fair weather when ambient temperature showed a clear sinusoidal fluctuation (Fig. 9). Room temperature changed moderately but evidently higher in the afternoon than at other times. The building ventilation rate generally followed temperature as the maximum ventilation occurred in the afternoon between 12:00 and 18:00 and the minimum occurred early in the morning between 3:00 and 6:00 (Fig. 8). There was a strong inverse relationship between H_2S concentration and building ventilation rate.

Table 3. Correlation coefficients between hydrogen sulphide concentrations and other variables.

	Pig herd		Room temperature	Building ventilation	SLG 1 concentration
	Inventory	Total mass			
Building 3B					
Room temperature	0.36*	-0.65*			
Building ventilation	0.24*	-0.38*	0.86*		
SLG 1 concentration	0.14	-0.20*	-0.12	-0.37*	
SLG 2 concentration	0.04	0.08	-0.43*	-0.69*	0.80*
Building 4B					
Room temperature	0.08	-0.47*			
Building ventilation	-0.14	-0.25*	0.85*		
SLG 1 concentration	0.38*	-0.25*	-0.19	-0.47*	
SLG 2 concentration	0.50*	-0.40*	-0.06	-0.40*	0.95*

SLG 3 H_2S concentrations are not included, because of small quantity of data.
*Statistically significant correlation ($P<0.05$)

The diurnal variations of H_2S concentration of pattern 2 (Fig. 10) were similar but less dominant than pattern 1. The maximum APM concentration was 430 ppb at 6:00 for SLG 3 in 4B. The ratio of maximum to minimum APM concentrations was always less than two with pattern 2. There were smaller differences between minimum and maximum ventilation rates (Fig. 10). Greater variations of ambient temperatures occurred with pattern 2 (Fig. 11) as compared with pattern 1.

Pattern 3 (Fig. 12) occurred during cloudy or rainy weather, when diurnal variations of ambient and room temperature fluctuations were the lowest (Fig. 13). The APM concentrations for pattern 3 days exhibited little variation with time of day, similar to the variation in ventilation rate.

Pattern 4 (Fig. 14) was only observed in 4B in April, May, and June. It was characterised by the maximum H_2S concentrations occurring in the afternoon and evenings instead of early morning. Likewise, the room and ambient temperatures (Fig. 15) and building ventilation rate (Fig. 14) also were the highest during the same time. The unique characteristic of pattern 4 is that, for an unknown reason, higher concentrations corresponded to higher ventilation rates.

Spatial variations

The PM H_2S concentrations at SLG 1 and SLG 2 were well correlated (0.80 to 0.95) with each other because both sampling locations were beneath the floor. The absolute DM concentration differences between any two of three sampling locations were evaluated (Table 5). The minimum and maximum absolute differences in Table 5 were calculated from DMs in the same day. The maximum difference was 271 ppb between SLG 1 and SLG 2 in 3B. It was 265 ppb between SLG 3 and SLG 1 in 4B. The DM concentration differences between any two sampling locations ranged from 20±6 to 132±17 ppb. These data indicated that there existed a significant spatial variation of H_2S concentration in the buildings.

Temporal variation was introduced into the study of spatial variations because sampling of gas concentrations was conducted with a 10 or 15 min time lag between locations. Nevertheless, spatial differences can be detected given a sufficient number of samples. Significant spatial H_2S concentration variations, indicated by absolute differences in ADM concentrations (Table 5) that were significantly greater than zero, agree with prior research on ammonia (De Praetere and van Der Biest 1990).

Based on the spatial variations in H_2S concentration observed in swine buildings in this study, it is important to carefully consider sampling locations in future studies. The measurement location should be in the animal zone when investigating animal exposure to H_2S gas. Single spot measurements are insufficient to represent mean concentration in a large swine building.

Table 4. Distribution of number of days in each month related to the four diurnal patterns of hydrogen sulphide concentration.

	March	April	May	June	July	Aug	Sept	Total
Building 3B								
Pattern 1	2	0	13	13	14	15	5	62
Pattern 2	2	7	5	6	8	3	7	38
Pattern 3	2	2	3	1	2	10	4	24
Building 4B								
Pattern 1	0	6	11	0	3	6	8	34
Pattern 2	0	3	5	4	3	9	1	25
Pattern 3	0	4	5	3	0	6	2	20
Pattern 4	0	1	4	11	0	0	0	16
Total								
Pattern 1	2	6	24	13	17	21	13	96
Pattern 2	2	10	10	10	11	12	8	63
Pattern 3	2	6	8	4	2	16	6	44
Pattern 4	0	1	4	11	0	0	0	16

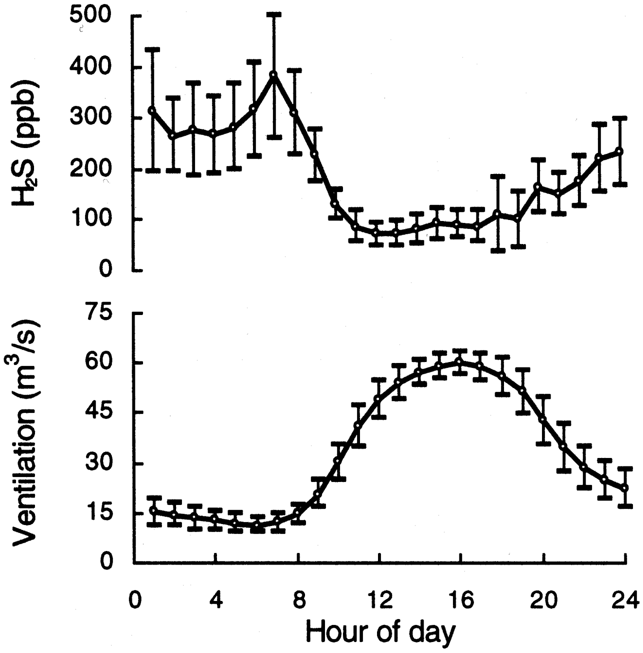

Fig. 8. Pattern 1 diurnal variations (mean±2SE) of hydrogen sulphide concentration at wall fans and associated building ventilation rates for building 3B.

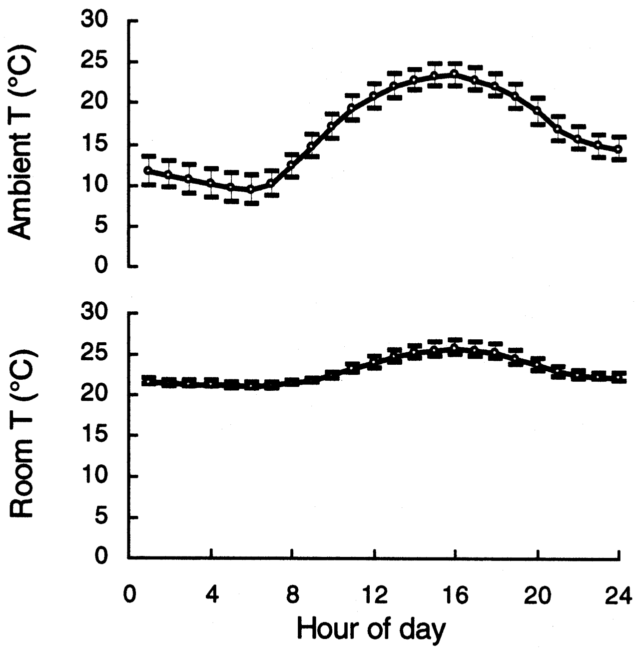

Fig. 9. Ambient and room temperatures (mean±2SE) associated with Pattern 1 diurnal variations for building 3B.

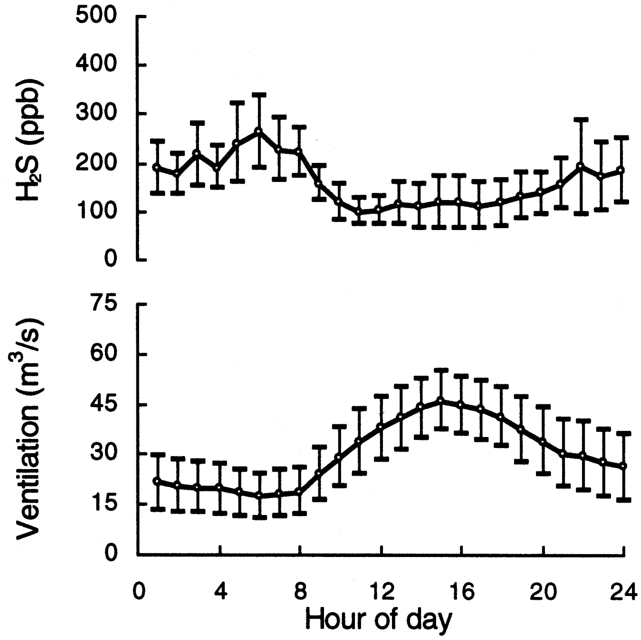

Fig. 10. Pattern 2 diurnal variations (mean±2SE) of hydrogen sulphide concentration at wall fans and associated building ventilation rates for building 3B.

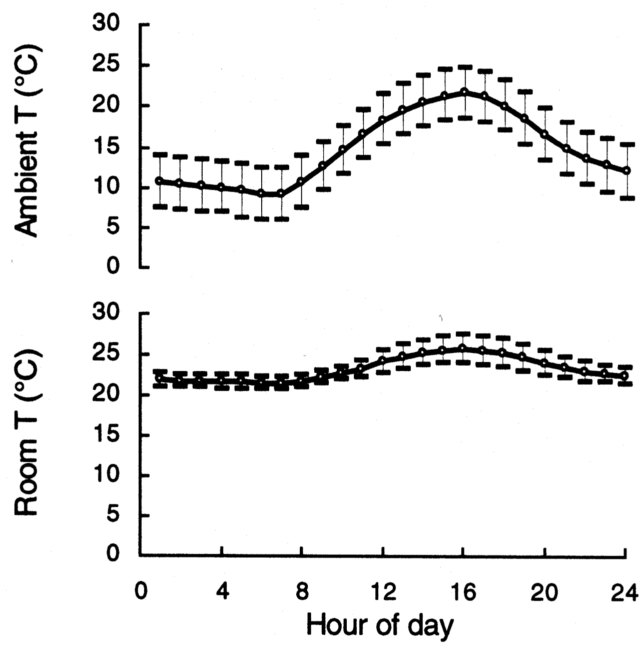

Fig. 11. Ambient and room temperatures (mean±2SE) associated with Pattern 2 diurnal variations for building 3B.

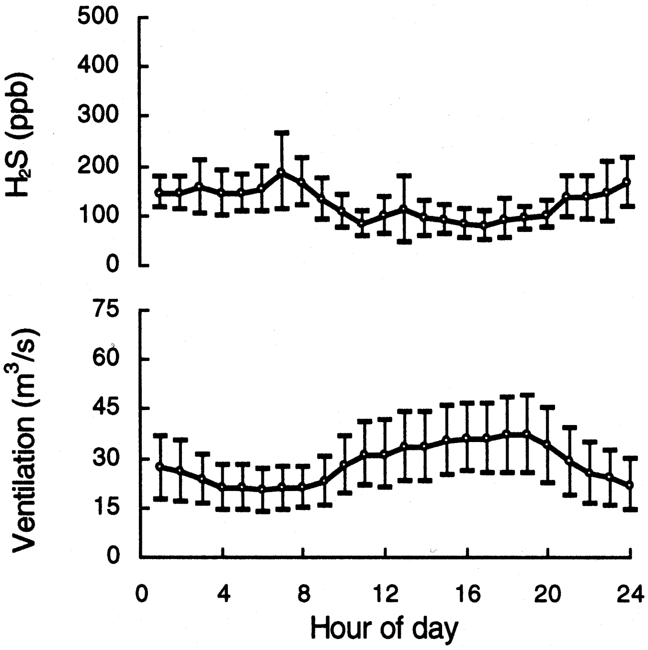

Fig. 12. **Pattern 3 diurnal variations (mean±2SE) of hydrogen sulphide concentration at wall fans and associated building ventilation rates for building 3B.**

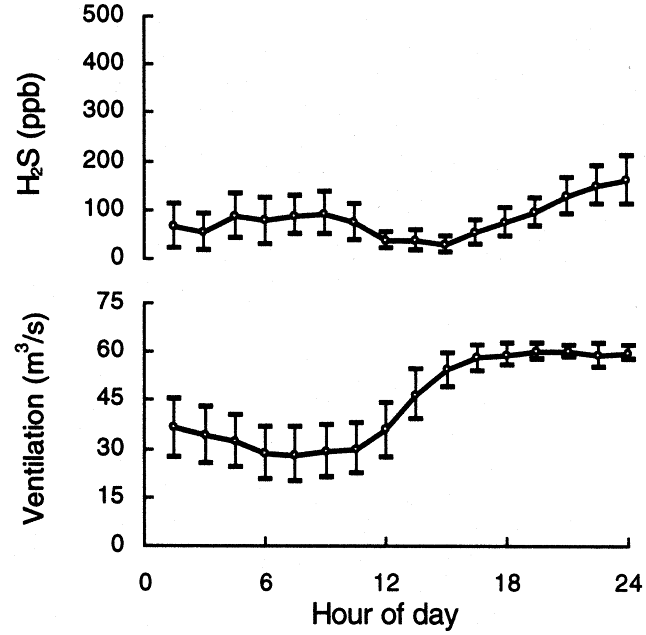

Fig. 14. **Pattern 4 diurnal variations (mean±2SE) of hydrogen sulphide concentration at pit fans and associated building ventilation rates for building 4B.**

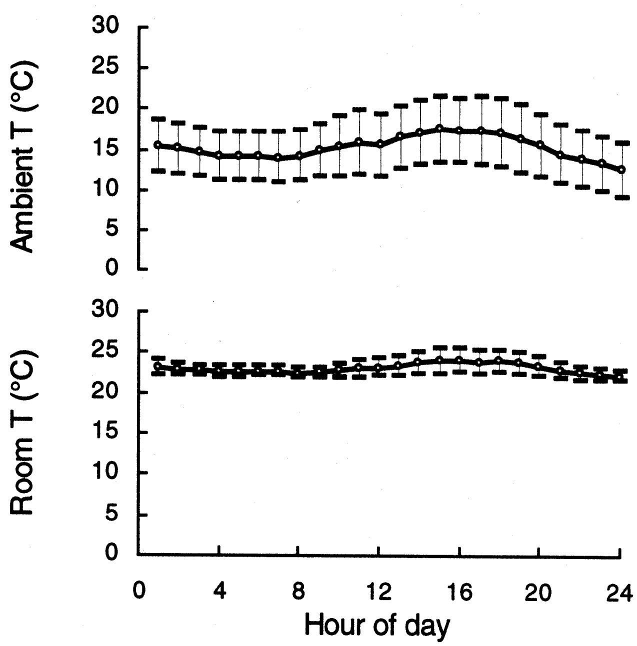

Fig. 13. **Ambient and room temperatures (mean±2SE) associated with Pattern 3 diurnal variations for building 3B.**

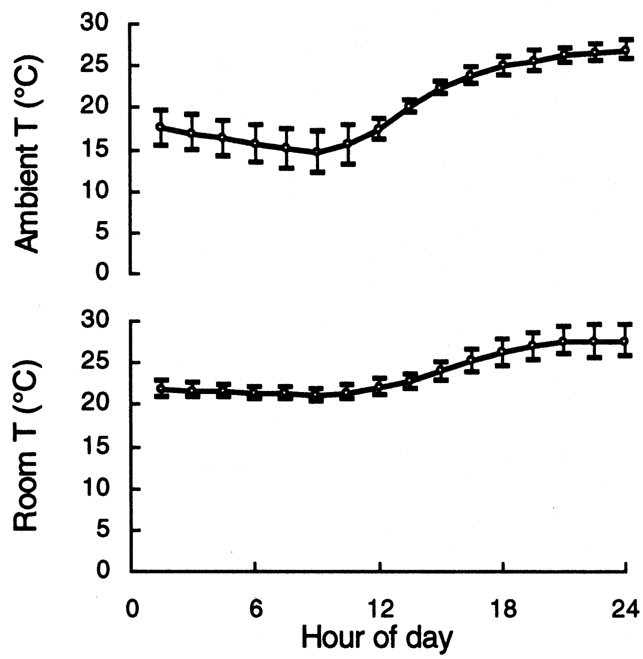

Fig. 15. **Ambient and room temperatures (mean±2SE) associated with Pattern 4 diurnal variations for building 4B.**

Table 5. Absolute differences of daily mean (DM) concentrations between any two sampling locations.

Locations	Number of days	Hydrogen sulphide concentration differences (ppb)		
		Mean±2SE	Minimum	Maximum
Building 3B				
SLGs 1 and 2	124	68±9	2	271
SLGs 2 and 3	87	56±11	0	259
SLGs 1 and 3	87	41±8	0	181
Building 4B				
SLGs 1 and 2	95	67±13	1	218
SLGs 2 and 3	38	20±6	0	85
SLGs 1 and 3	38	132±17	52	265

CONCLUSIONS

The following conclusions were drawn from this study:

1. The average daily mean building H_2S concentrations were 180±16 and 232±39 ppb for 3B and 4B, respectively, and were similar to the results of prior studies.
2. The daily mean building concentrations ranged from 18 to 1107 ppb.
3. Building ventilation rate was the obvious primary factor in creating a saddle-shaped seasonal concentration pattern from April to September.
4. The period mean building H_2S concentrations ranged from 1 to 1527 ppb, or one to two orders of magnitude less than occupational safety thresholds.
5. Diurnal patterns of H_2S concentrations that were correlated to inverse building ventilation patterns were observed 92% of the time. Concentration patterns were proportionally correlated to building ventilation 8% of the time.
6. Differences in H_2S concentrations were observed between sampling location groups. The average daily mean concentration differences between any two sampling location groups ranged from 20±6 to 132±17 ppb.
7. Based on the temporal and spatial variations of H_2S concentrations observed in this study, more accurate representation of mean building concentrations is obtained with long-term measurements and multiple sampling locations.

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