Correlation between odour intensity assessed by human assessors and odour concentration measured with olfactometers

Q. Zhang[1], J.J.R. Feddes[2], I.K. Edeogu[2] and X.J. Zhou[1]

[1]Department of Biosystems Engineering, University of Manitoba, Winnipeg, Manitoba, Canada R3T 5V6; and [2]Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, Alberta, Canada T6G 2P5.

Zhang, Q., Feddes, J.J.R., Edeogu, I.K. and Zhou, X.J. 2002. **Correlation between odour intensity assessed by human assessors and odour concentration measured with olfactometers**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **44**: 6.27-6.32. Odour data were collected on four swine farms to determine the relationship between odour intensity assessed by trained human odour assessors (Nasal Rangers) and odour concentration measured with olfactometry. Odour intensity was assessed by two or more Nasal Rangers using the 8-point n-butanol reference scale in the field, as well as in the laboratory for odour samples collected in Tedlar bags. The field odour intensity did not correlate well with the odour concentration measured with olfactometers. When high odour intensity was detected by the Nasal Rangers in the field, the odour concentration measured from the bagged samples changed little. In other words, the odour samples taken in Tedlar bags could not capture instantaneous bursts of strong odour in the field. Odour intensity of bagged samples measured by Nasal Rangers in the laboratory correlated well with the odour concentration measured with olfactometers and the relationship could be adequately predicted by two commonly used models - the Weber-Fechner model and the Stevens model. When a strong source odour was diluted, its intensity decreased linearly with the dilution level on a log-scale. **Keywords:** swine odour, human assessor, olfactometer, n-butanol scale.

Des données d'odeur ont été recueillies sur quatre fermes porcines pour déterminer la relation qui existe entre l'intensité de l'odeur évaluée par des évaluateurs humains (évaluateurs d'odeur) et la concentration d'odeur mesurée avec un olfactomètre. L'intensité d'odeur a été évaluée au champ par deux évaluateurs d'odeur ou plus qui ont utilisé une échelle de référence au n-butanol de huit points et, en laboratoire en évaluant des échantillons d'air recueillis dans des sacs Tedlar. L'intensité d'odeur évaluée au champ n'a pu bien prédire la concentration d'odeur mesurée à l'aide des olfactomètres. Lorsque des odeurs d'intensité élevée étaient détectées par les évaluateurs d'odeur au champ, les concentrations d'odeur mesurées à partir des échantillons d'air des sacs Tedlar, elles, variaient peu. En d'autres termes, les échantillons d'odeur provenant des sacs Tedlar ne pouvaient capter les effluves de fortes odeurs perçues de manière instantanée au champ. L'intensité d'odeur des échantillons en sac mesurée en laboratoire par les évaluateurs d'odeur s'est avérée être un bon prédicteur de la concentration d'odeur mesurée avec les olfactomètres et des relations ont pu être définies de manière adéquate en utilisant deux modèles courants - le modèle Weber - Fechner et le modèle Stevens. Lorsqu'une source d'odeur de forte intensité était diluée, son intensité décroissait linéairement avec son taux de dilution sur une échelle logarithmique.

INTRODUCTION

Odour from swine operations is a complex mixture of many different odourous compounds resulting mainly from the anaerobic decomposition of swine manure. Odour intensity depends on the concentration of each compound and the combination of these compounds as well. As both the concentration and the combination of these compounds are highly variable upon the environmental conditions and management practices, the intensity and characters of odour vary greatly. This makes odour measurement a serious challenge to researchers and regulatory agencies. Currently, dynamic-dilution olfactometers are considered to be the standard method of odour measurement. To use olfactometers for measuring odour from swine production units a number of factors need to be considered. One of the most important factors is odour dilution when samples are collected in Tadlar bags for olfactometer measurement. Odour sampled over any period of time is a composite sample of the ambient air. Over the sampling period, the ambient air contains a mixture of varying concentrations of odourous and non-odourous gases. The presence and concentration of odourous gases in the sampled air is adversely affected by the direction and speed of the wind. Instantaneous changes in wind direction and speed during the sampling period imply that the concentration of odourous gases collected will vary from moment to moment. Hence, it is almost certain that the odour perception of an observer at the downwind sampling site will differ from the olfactometer measurement of the composite sample collected at the same site over the same time period.

Another issue of using olfactometers is the interference of inherent residual odour in sampling bags. Often the concentrations of odour samples collected downwind from odour sources are low and consequently non-detectable with olfactometers. In such situations, the low levels of the bagged odour samples may be masked by the residual odour of the sampling bags (Nicolai et al. 2000).

A potentially more satisfactory method of evaluating odour directly in the field is quantifying the instantaneous odour intensity by using human sniffers. The human sniffing technique has been used by several researchers in their studies of livestock odours. There is a German guideline which describes specific procedures of determining field odour plumes by human sniffers (VDI 1993). Hartung and Jungbluth (1997) followed the German guideline to measure the odour plumes from dairy and cattle barns. Sniffers ranked odour intensity in the field based on a 6-point intensity scale suggested by German VDI Guideline 3882 (VDI 1992). Zhu et al. (2000) used seven trained human

Table 1. Eight point n-butanol odour intensity referencing scale.

Level	n-butanol concentration in water* (ppm)	Annoyance scale
0	0	no odour
1	120	not annoying
2	240	a little annoying
3	480	a little annoying
4	960	annoying
5	1940	annoying
6	3880	very annoying
7	7750	very annoying
8	15500	extremely anoying

* Concentration in air (headspace) is approximately 10% of concentration in water

sniffers to conduct on-site odour intensity measurement. The sniffers were trained to rank odour intensity on a scale of zero to five (0: no odour; 1: very faint; 2: faint; 3: distinctly noticeable; 4: strong; 5: very strong odour). Resident sniffers who received limited training were used by Guo et al. (2001) in monitoring odour occurrences in a livestock production area. They used a relatively simple intensity scale of 0 to 3 (0: no odour; 1: faint odour; 2: moderate to strong odour, and 3: very strong odour). St. Croix Sensory Inc. (Stillwater, MN) developed a method for quantifying odour intensity using n-butanol reference scales. This method requires the human sniffers to be trained and certified as Nasal Rangers. The use of the n-butanol reference scales enables Nasal Rangers to quantify odour intensity instantaneously and obtain immediate results at relatively low cost.

The objectives of this study were to investigate the relationship between odour intensity assessed by Nasal Rangers and odour concentration measured with olfactometers and to determine if bagged odour samples used for olfactometer measurement reflected the odour levels in the field.

METHODOLOGY

Site description

Four sites were selected for this study: two swine operations in Southern Manitoba (MB-A and MB-B) and two swine operations in Central Alberta (AB-A and AB-B). Site MB-A was a furrow to early wean swine operation. The facility was two years old with bushes and trees around the barn and manure storage. The barn was mechanically ventilated with wall mounted exhaust fans. Manure was handled as liquid in shallow gutters (1-3 months) and stored in an uncovered earthen storage. The site was surrounded by flat cropland.

Site MB-B was a two-year old farrow to wean operation, which consisted of a nursery barn, a farrow barn, and a dry sow barn. The barns had roof mounted exhaust fans (chimneys) for ventilation. Manure was flushed approximately every two months from shallow gutters to a straw covered two-cell earthen storage. There was a windbreak (bushes and trees) around the barns and manure storage. A circle of 5-km radius around the site barn was mostly flat cropland.

Site AB-A was a farrow to finish operation with an earthen manure storage facility. There were few other livestock operations in close proximity to this site. The topography of the area showed a relatively flat terrain east, west, and south of the site. North of the site the terrain sloped gently southward. Most of the land east and south of the site was cultivated with cereal crops. A thick grove of trees formed a shelterbelt directly west of the site.

Site AB-B was a farrow to finish facility with an open concrete tank for manure storage. The area north and west of the site was hilly. East of the site the terrain sloped gently eastward but was relatively flat up to about 500 m to the south. Most of the land surrounding the site is used for crop research and grazing beef cattle.

Odour intensity measurement

The Nasal Rangers (human odour assessors) who participated in this study attended an Odour School conducted by St. Croix Sensory Inc. (Stillwater, MN). Each Nasal Ranger was trained to use the ASTM Odor Intensity Referencing Scale and ASTM E544-99 Standard (ASTM 1997) for referencing suprathreshold odour intensity. An 8-point odour intensity referencing scale was used in this study (Table 1). The n-butanol references were prepared as mixtures of 8 different concentrations of n-butanol and water (ASTM 1997) in 45 mL glass bottles with Teflon coated lids. To take a measurement of odour intensity, the Nasal Ranger put on a carbon filtered air mask to clear his/her nose for about two minutes. And then he/she removed the mask, sniffed the air being measured for about 30 seconds, and assigned an intensity level (0 to 8) to the sample. At least two Nasal Rangers were employed for each intensity measurement and each Nasal Ranger took two or more sniffs. In other words, one intensity measurement was the average of at least four sniffs.

Prior to assessing odour intensity, each Nasal Ranger's measurement accuracy (i.e. sensitivity and consistency) was evaluated. The evaluation was conducted by presenting three unknown n-butanol samples from the 8-point reference scale to the Nasal Rangers. An assessment within one deviation of the actual sample intensity on the scale was considered acceptable.

Odour concentration measurement

A single-port olfactometer (AC'SCENT, St. Croix Sensory, Inc., Stillwater, MN) with six trained assessors was used for odour concentration measurement at sites MB-A and MB-B. Odour concentration measurements were conducted using an 8-port olfactometer and 8 panelists for sites AB-A and AB-B. This olfactometer was designed according to ASTM and CEN (European) standards (Feddes et al. 2000). Samples in 10-L Tedlar bags were used for olfactometer measurement. The triangular forced-choice method was used to present samples to the assessors, with a 3-s sniff time. Panelists were selected and re-evaluated periodically following the procedure of CEN (1999). For each panel session, data were retrospectively screened by comparing assessors' individual threshold estimates with the panel average (CEN 1999). Odour concentration was expressed as odour units per unit volume (OU_E/m^3) according to CEN (1999) standards.

Sample collection

A total of 155 samples was collected in 10-L Tedlar bags from the four sites during a period from June to October, 2001, of

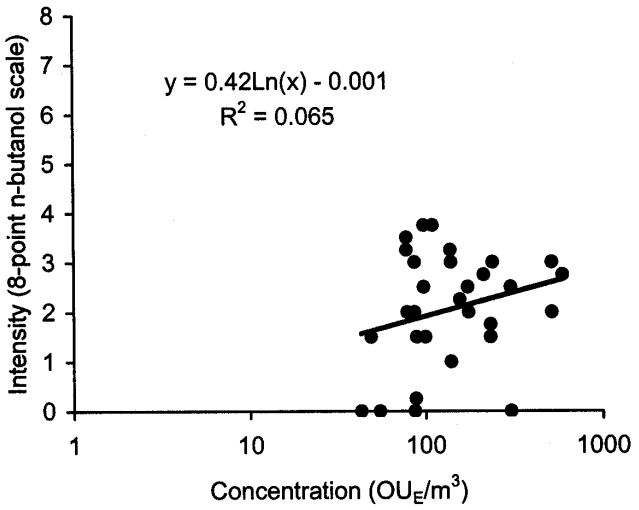

Fig. 1. Relationship between odour intensity assessed by Nasal Rangers in the field and odour concentration measured with olfactometer for site MB-A.

which 26 were taken from barn exhaust fans and 129 downwind from the facilities. Downwind samples were taken at distances from 10 m to a maximum of 2 km downwind from odour sources. Each sampling location was selected based on the detection of odour by the Nasal Rangers, i.e. samples were taken only at locations where the Nasal Rangers detected odour in the air. While the Nasal Rangers were assessing the odour intensity of the ambient air at a selected location (field odour intensity), odour samples were collected simultaneously into Tedlar bags using vacuum chambers. The bagged odour samples were shipped to olfactometry laboratories for analysis within 24 hours.

The average time to collect a sample (fill a 10 L Tedlar bag) was about 5 minutes in sites MB-A and MB-B, and 1.5 minutes in the other two sites. A bagged sample, therefore, reflected the odour strength "averaged" over the sampling period. However, the odour intensity measured by the Nasal Rangers in the field was instantaneous. In other words, the intensity measured by the Nasal Rangers might not be the "true" intensity of the bagged sample if the odour level in the air or environmental conditions changed during sample collection. To determine the true relationship between odour intensity and odour concentration, odour intensity of each bagged sample was assessed by the Nasal Rangers in the laboratories before the sample was tested for odour concentration on the olfactometer.

An odour is diluted when it is transported in the atmosphere and the odour intensity decreases as it is diluted. The rate of decrease in odour intensity with dilution indicates the persistence of odour. A more persistent odour would have a greater downwind impact (longer "hang" time in the air). To determine the odour persistence, thirteen strong source samples were diluted from their original strength to the minimum odour concentration that could be detected by the olfactometer (~8 OU_E/m^3). Depending on the original odour strength, up to 8 sub (diluted) samples were generated from one strong source sample and the odour intensity of each sub sample was then evaluated by the Nasal Rangers.

RESULTS and DISCUSSION

Odour intensity and odour concentration are the two most important properties of an odour. Much research has been conducted to correlate the two properties for livestock odours (Bundy et al.1997; Nicolai et al. 2000; Guo et al. 2001). Nicolai et al. (2000) and Guo et al. (2001) showed that the Weber-Fechner logarithmic model provided the best mathematical description of the combined building and manure storage odour from swine operations. The Weber-Fechner model has the form of:

$$I = k_1 \log_{10} C + k_2 \quad (1)$$

where:

I = intensity of sensation (8-point n-butanol scale),
C = concentration of stimulus (OU_E/m^3, measured with olfactometers), and
k_1, k_2 = constants.

Equation 1 indicates that the correlation between odour intensity (I) and concentration (C) should be examined on a log-linear scale. Therefore, the logarithmic value of odour concentration ($\log_{10}C$) will be used in the following discussion.

Relationship between odour intensity and odour concentration

The field (downwind) odour intensity assessed by the Nasal Rangers represented the instantaneous odour level at *a certain time* during sample collection. Figure 1 shows collected data for site MB-A and indicates that the field odour intensity did not correlate well with the odour concentration measured with olfactometers, which represented the odour level averaged during *the entire sampling period*. The same observation was made for the other three sites. The highest coefficient of determination (R^2 value) was 0.28 for site AB-B and the lowest 0.064 for MB-A. When data from all four sites were pooled, the coefficient of determination was only 0.049. When the pooled intensity data were plotted against the concentration, the slope of the curves was flat (–0.072 and not significantly different from 0 at $P>0.05$) (Fig. 2). This indicates that when a high odour intensity was detected by the Nasal Rangers in the field, the odour concentration measured from the bagged samples changed little. In other words, the composite samples taken in Tedlar bags could not capture instantaneous bursts of strong odour in the field.

Comparisons between the field odour intensity to that of bagged samples measured in the laboratory also indicated that odour was diluted when collected in Tedlar bags, especially when strong odour (>level 5) was detected by the Nasal Rangers (Fig. 3). For example, a bagged sample collected at site AB-A had an intensity of 3.5, whereas the corresponding field odour intensity was 7.0. However, the intensity of bagged samples was higher than the field intensity when the field odour was weak (<level 2) (Fig. 3). This was attributed to the residual odour of Tadlar bags. It was found that odour intensity of clean empty bags varied from 0.5 to 2.8, with a mean value of 1.2. This means that odour intensity of a bagged sample would be completely masked by the residual odour of the bag if its intensity was lower than 1.2. This also indicates the potential bias of using Tedlar bags for collecting odour samples. Keener

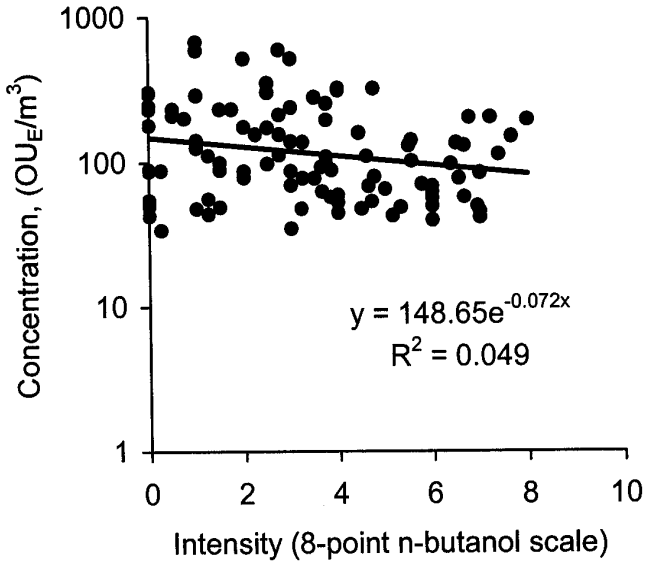

Fig. 2. Variation of odour concentration of bagged samples with field odour intensity assessed by Nasal Rangers (combined data for all four sites).

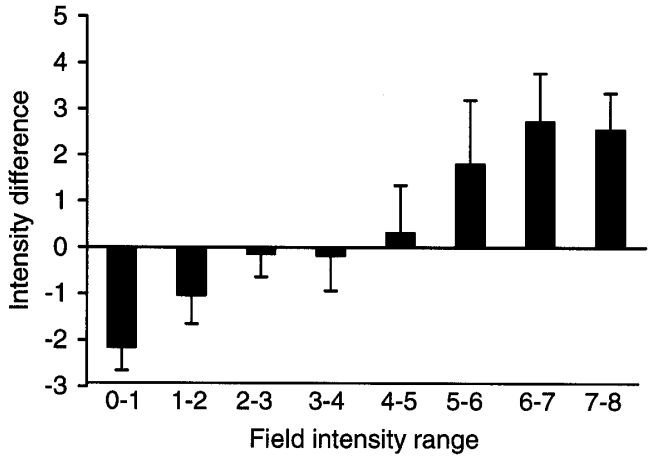

Fig. 3. Difference between odour intensity measured in the field and odour intensity of bagged samples measured in laboratory (field - laboratory) (T: one standard deviation).

et al. (2002) showed that Tedlar bags emitted acetic acid and phenol and they might bias air samples collected for olfactory analysis.

The intensity of bagged samples correlated well with the odour concentration measured with olfactometers (Fig. 4). The coefficients of determination were 0.87, 0.73, 0.60, and 0.33 for sites MB-A, MB-B, AB-A, and AB-B, respectively. When data were pooled from the four sites, the overall R^2 value was 0.61 (Fig. 5).

Odour persistence

The odour intensity decreased linearly with the dilution level (on a log scale) when a strong source sample was diluted

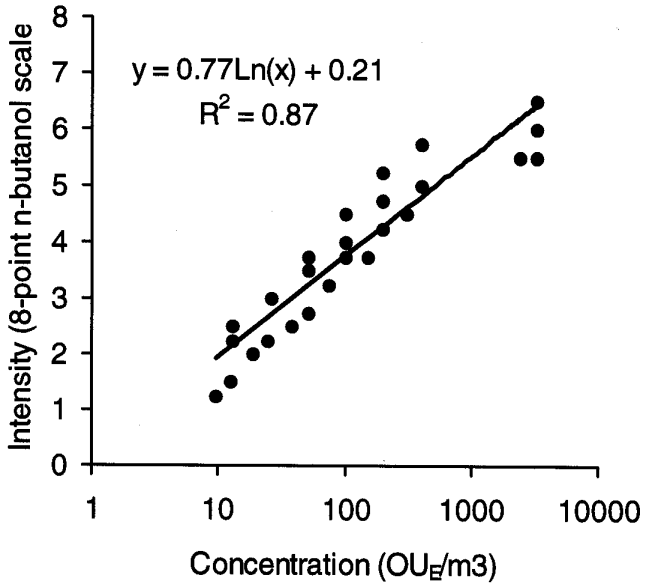

Fig. 4. Relationship between odour intensity of bagged samples assessed by Nasal Rangers in the laboratory and odour concentration measured with olfactometer for site MB-A.

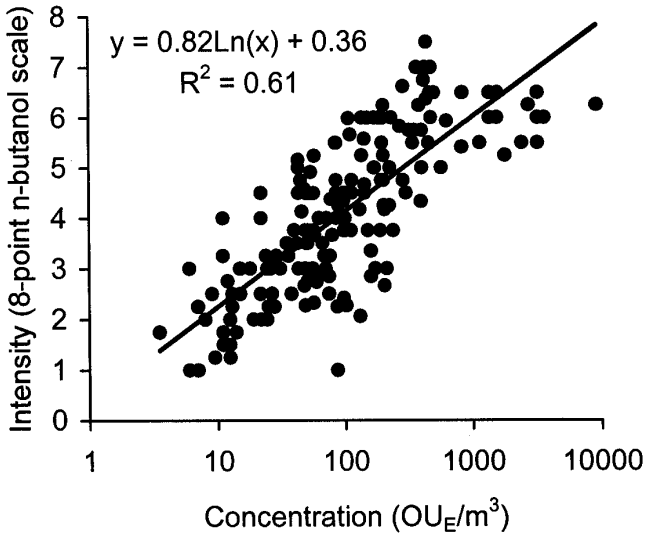

Fig. 5. Relationship between odour intensity of bagged samples assessed by Nasal Rangers in the laboratory and odour concentration measured with olfactometer for all four sites.

(Fig. 6). The slope of the curve indicated the persistence of odour: the greater the slope, the less persistent the odour. For 13 source samples that were diluted between 8 to1088 times, the average slope was -1.65 (standard deviation S = 0.40). This means that the odour intensity decreased by 1.65 on the 0-8 scale for every 10-fold dilution.

Prediction models

Predictive models may provide a tool for researchers and regulatory agencies to relate odour concentrations predicted by

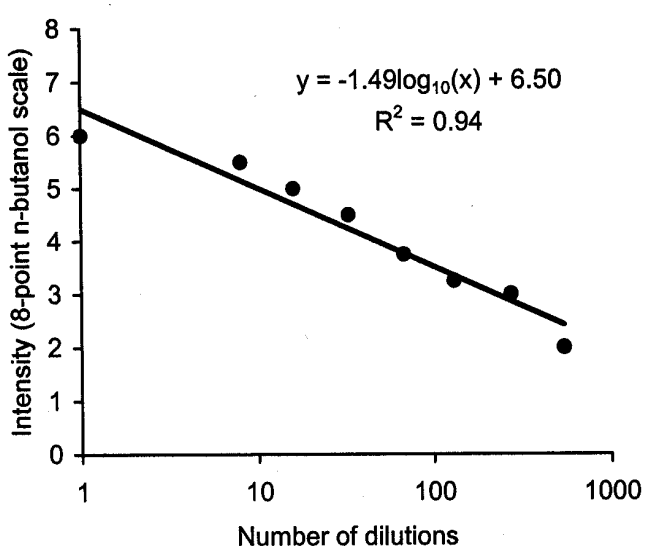

Fig. 6. Decrease in odour intensity when a strong odour sample was diluted.

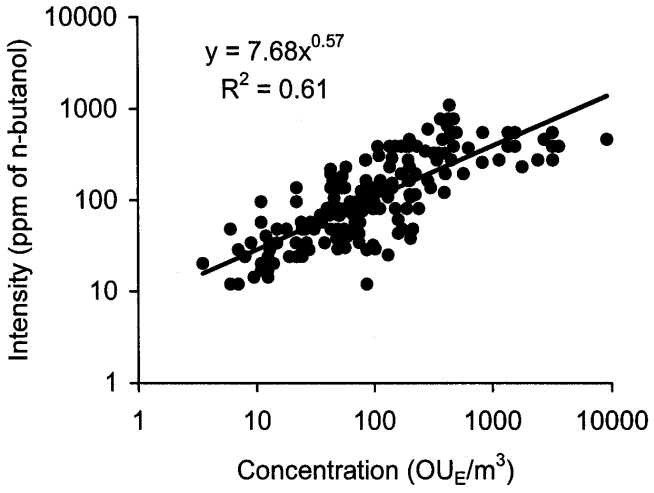

Fig. 7. Relationship between odour intensity of bagged samples expressed as equivalent n-butanol concentration (in air) and odour concentration measured with olfactometer for all four sites.

dispersion models to odour intensity levels or ultimately to odour annoyance levels (Zhu et al. 2000; Guo et al. 2001). Nicolai et al. (2000) used three models to predict the relationship between odour concentration (OU_E/m^3) and a 5-point n-butanol intensity scale for swine odour. For combined building and manure storage odour sources, they selected the Weber-Fechner model as the best model for low odour levels (<100 OU_E/m^3). Guo et al. (2001) also reported that the Weber-Fechner model provided the best fit to their experimental data for swine and cattle odours. To determine the parameters of the Weber-Fechner model (Eq. 1), odour intensity of bagged samples, which reflected the true intensity of odour samples, were plotted against odour concentration measured with

Table 2. Comparisons between Stevens model and Weber-Fechner model.

Odour intensity		Predicted odour concentration (OU_E/m^3)	
Level*	ppm**	Stevens	Weber-Fechner
1	12	2.2	2.1
2	24	7.4	7.0
3	48	24.9	23.5
4	96	84.0	78.4
5	194	288.7	261.5
6	388	974.0	872.3
7	775	3278.6	2910.0
8	1550	11061.3	9708.2

* 8-point n-butanol scale
** n-butanol concentration in air

olfactometers (Fig. 5). The two parameters were determined to be $k_1 = 0.82$ and $k_2 = 0.36$. It should be noted that these two values were valid only for the 8-point n-butanol intensity scale defined in Table 1. Other intensity scales have been used by different researchers (e.g. 5-point n-butanol scale). To compare the current model with others, the intensity levels were converted to equivalent n-butanol concentration (in air) according to Table 1. The relationship between the intensity level and the n-butanol concentration was approximately logarithmic, as shown in Table 1. Therefore, the logarithmic value of intensity (I) should be used in Eq. 1 when the intensity is expressed as ppm of n-butanol concentration:

$$\log_{10} I_b = k_3 \log_{10} C + \log_{10} k_4 \quad (2)$$

where:

I_b = odour intensity expressed as ppm of n-butanol in air, and
k_3, k_4 = constants.

Equation 2 may be written as:

$$I_b = k_4 C^{k_3} \quad (3)$$

Equation 3 is the commonly used Stevens (1960) model (power law). The two parameters of the Stevens model were determined to be $k_3 = 0.57$ and $k_4 = 7.68$ (Fig. 7). The coefficient of determination (R^2) was 0.61, which is the same as that for the Weber-Fechner model. The prediction by the Stevens model was almost identical to that by Weber-Fechner model (Table 2). The prediction by the current models was in close agreement with that by Nicolai et al. (2000) at low odour levels (< 100 OU_E/m^3) and was higher than those by both Nicolai et al. (2000) and Guo et al. (2001) at high odour levels (Fig. 8).

CONCLUSIONS

1. There was little correlation (R^2=0.049) between the odour concentration of bagged samples measured with olfactometers and the odour intensity assessed by Nasal Rangers in the field. The bagged samples could not capture instantaneous high odour levels in the field.

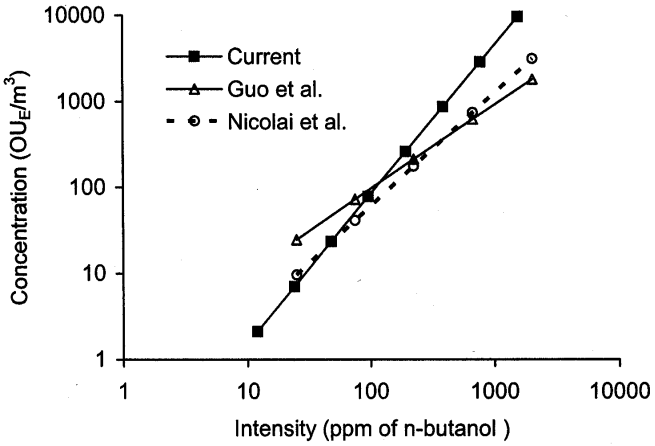

Fig. 8. Comparisons between three prediction models.

2. There was a good correlation (R^2=0.61) between the odour concentration measured with olfactometers and the odour intensity of bagged samples assessed by Nasal Rangers in the laboratory.
3. The relationship between odour concentration (OU_E /m^3) measured with olfactometers and odour intensity assessed by Nasal Rangers using the 8-point n-butanol intensity scale could be adequately predicted by both the Weber-Fechner model and the Stevens model.

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