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Substrate Properties of Stable Fly (Diptera: Muscidae) Developmental Sites Associated With Round Bale Hay Feeding Sites in Eastern Nebraska

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Substrate Properties of Stable Fly (Diptera: Muscidae) Developmental Sites Associated With Round Bale Hay Feeding Sites in Eastern Nebraska

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ABSTRACT   Residues at sites where stationary feeders were used to provide hay as supplemental forage for cattle during the winter are developmental substrates for immature stable flies, *Stomoxys calcitrans* (L.), in the central United States. Spatial patterns in physical (substrate depth, temperature, water content), chemical (pH, electrical conductivity [EC_{lab}], total nitrogen [N] and carbon [C], ammoniacal nitrogen [NH_4-N], extractable phosphorus [P]), and biological (microbial respiration rate) substrate properties for two feeding sites were estimated and the correlations between these properties and adult emergence were characterized. Hay feeding sites had a circular footprint with residues extending ≈7 m from the feeder. With the exception of extractable P and total N, all substrate properties exhibited spatial patterns centered on the feeder location. Adult stable fly emergence densities were significantly correlated with substrate microbial respiration rate, NH_4-N concentration, EC_{lab}, total C concentration, pH, and moisture content. Logistic regression indicated that EC best predicted the probability of stable flies emerging from a substrate and that the other properties did not provide additional information. A better understanding of the physical, chemical, and biological conditions needed for stable fly larval development may help in identifying previously unrecognized developmental habitats and management of this pest. Targeted implementation of management practices such as sanitation and chemical treatments can be applied to smaller areas reducing labor and improving cost effectiveness.

KEY WORDS   *Stomoxys calcitrans*, larval developmental sites, spatial variability

Infestations of stable flies, *Stomoxys calcitrans* (L.) (Diptera: Muscidae), on pasture cattle have become more frequent over the last 40 yr (Hall et al. 1982). Biting and blood feeding by stable flies reduce weight gains in grazing cattle (Campbell et al. 2001) and lost productivity has been estimated to cost the cattle industry up to $2 billion U.S. dollars a year (Taylor et al. 2012). Few control measures are available for stable fly (Broce et al. 2005, Foil and Younger 2006, Hogsette et al. 2008). Because adults prefer to feed on the lower legs of cattle where control agents are quickly dissipated by wet grass or standing water, no effective methods are available for host protection in pasture or range environments (Campbell and Hermanussen 1971). Control of stable flies during the larval stage, when they are concentrated in suitable breeding habitats and relatively immobile, with sanitation practices that eliminate breeding habitats is the preferred option for managing this pest.

In feedlot environments, stable fly larvae develop in accumulations of fermenting organic materials such as silage and spilled feed, often mixed with manure (Meyer and Petersen 1983). In pastures, Hall et al. (1982) reported immature stable flies developing in rotting hay at the base of large round bales stored in the field. In the central United States, stationary feeders are frequently used to provide large round hay bales for supplemental forage during the winter. As the cattle feed at these sites, a portion of the hay falls to the ground and is mixed with manure and urine creating a suitable substrate for stable fly development the next spring (Broce et al. 2005). These winter hay feeding sites have been identified as a major source of early summer stable flies (Taylor and Berkebile 2011). In eastern Nebraska, seasonal stable fly populations are bi-modal with a large peak in early summer and a smaller peak in late summer (Taylor et al. 2007). Larval developmental sites for flies observed before hay feeding sites become productive in spring and after they cease being productive in midsummer (Taylor and Berkebile 2011) have not been identified.

Understanding substrate properties of known stable fly developmental habitats may help identify unrecognized habitats and better understand the population

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dynamics of this pest. Initial descriptions of substrate properties and stable fly phenology for large round bale hay feeding sites are available. Broce et al. (2005) described hay feeding sites as being from 13 to 262 m^2 in size with a substrate thickness of 25 cm. They monitored substrate temperature, stable fly emergence, and dispersal from hay feeding sites but did not further describe substrate properties. Talley et al. (2009) presented a conceptual model for hay feeding sites as being composed of three concentric rings surrounding the hay feeder. Each ring was described as having a distinct substrate composition and depth. Within each ring, they measured adult emergence, substrate temperature, moisture, pH, and fecal coliform concentration. They reported that substrate depth decreased, pH and moisture increased, and stable fly emergence, temperature, and fecal coliform concentration did not change with distance from the feeder site. Variation in adult stable fly emergence densities within rings prevented detection of differences among rings. The role of microorganisms in the substrate was evaluated further by Romero et al. (2006). They found that female stable flies laid more eggs on microbially active substrate than on sterile substrate and larval development was dependent on the presence of active microorganisms. Taylor and Berkebile (2011) used the conceptual model of Talley et al. (2009) to study the phenology of stable fly larvae in hay feeding sites. They found that emergence of adult stable flies from these sites declined as the substrate decomposed during the summer and that spatial variability within a site resulted in inconsistent results among sites.

Apparent electrical conductivity (EC_a) is a physiochemical measurement that often correlates with substrate properties such as water content, salt content, organic matter content, and bulk density (Corwin et al. 2008). Apparent electrical conductivity is a quick, easy, and inexpensive measurement that can be coupled with spatial coordinates to obtain a geospatial map of a site. Spatial EC_a data can be used to develop sampling designs (Lesch et al. 1995). Regression analyses can be used to relate EC_a to substrate properties measured at the directed substrate sampling locations. These regressions can then be use to estimate substrate properties at the remaining EC_a locations (Wienhold and Doran 2008). Use of EC_a and directed sampling is an efficient method for delineating spatial patterns in substrate properties.

The objectives of the current study were to: 1) delineate spatial patterns in select physical, chemical, and biological substrate properties and 2) establish relationships between substrate properties and stable fly emergence at two representative hay ring feeder sites in eastern Nebraska.

Materials and Methods

The study was conducted in 2010 in a pasture located on the University of Nebraska, Agricultural Research and Development Center (Lat. 41.1425°, Long. −96.4539°) near Ithaca, NE. Soil was a Tomek silt loam. Two sites where cattle had been fed hay from round bale feeders during the previous winter were selected within the pasture. Sites were typical winter hay feeding sites and similar to those used in previous studies (Taylor et al. 2010; Taylor and Berkebile 2011). At each site, sixteen 15-m transects were established. Transects were parallel to one another and were spaced 1 m apart. On 3 June 2010, measurements were taken every 0.5 m along each transect resulting in 480 points arranged in a grid centered on the hay feeder location. At each sampling point, apparent electrical conductivity (EC_a) and temperature were measured by inserting a probe (Hanna Instruments, Woonsocket, RI) 10 cm into the substrate or soil (Arnold et al. 2005). Substrate depth was recorded at each sampling point by inserting a 0.3-cm-diameter steel rod into the substrate until soil was encountered.

The EC_a data were processed using the ESAP-95 (http://www.ars.usda.gov/Services/docs.htm?docid= 8918, verified 6 January 2012) software package (Lesch et al. 2000). Two components of the ESAP-95 software package, Response Surface Sampling Design (RSSD) and Calibrate, were used in this study. The ESAP–RSSD component uses response surface methodology to identify statistically optimum sampling locations (directed sampling) that reflect the spatial variability in EC_a (Corwin and Lesch 2003). Sampling location selection includes establishing a minimum grid size that effectively separates sampling points to eliminate autocorrelation. Parameters were examined using Moran's I to confirm that there was no autocorrelation among properties at the directed sampling locations. Properties at each site were modeled independently. At each site, substrate properties were measured for samples collected using two directed sampling designs each consisting of 12 of the 480 grid points. Samples from one design were used to calibrate ESAP and samples from the second design were used to validate ESAP.

Substrate samples were collected at each location by extracting a 10-cm-diameter by 10-cm-deep core. Samples were returned to the laboratory where substrate water content, laboratory electrical conductivity (EC_{lab}), pH, extractable P, total C, total N, inorganic N, and microbial respiration were determined. Substrate water content was determined gravimetrically by weighing, oven drying (105°C), and reweighing samples (Gardner 1986). Laboratory EC_{lab} and pH was determined in 1:1 water:substrate slurries by using a conductivity meter for EC_{lab} and a glass electrode for pH (Smith and Doran 1996). Extractable P was determined using the method of Bray and Kurtz (1945) with P concentration determined spectrophotometrically at 882 nm using the phosphomolybdate blue method (Murphy and Riley 1962). Inorganic N in one M KCl extracts was measured colorimetrically using a flow injection ion analyzer (Zellweger Analytics, Lachat Instruments Div., Milwaukee, WI). Nitrate-N was determined using the Cd reduction method (Mulvaney 1996). Total C and total N were measured by dry combustion (EA1112 Flash NC Elemental analyzer, Thermo Finnegan Scientific Inc., Waltham, MA) using air-dried, ground substrate. Microbial respiration was

determined by placing 10-g oven dry equivalent of substrate in a 1.8-liter jar sealed with a lid containing a rubber septum. Jars were incubated at 25°C and headspace CO_2 concentration determined after 0.25, 0.5, 1, and 2 h using a gas chromatograph equipped with an electron capture detector.

At each site, adult stable fly emergence patterns were determined by placing 0.25-m^2 emergence traps (Taylor and Berkebile 2011) at each of the 12 calibration sample points for 4 wk after substrate sampling. Traps were installed on 7 July 2010, serviced weekly, and adult stable flies were sorted by sex and counted. Season totals for each trap were used in the analysis.

Statistical Analysis. The ESAP–Calibrate program was used to develop site specific regression models relating EC_a to substrate characteristics at the 12 calibration sample points ($\alpha = 0.05$). Resulting regression models were used to estimate substrate characteristics at the unsampled grid points. Regression models were validated by regressing estimated values at the 12 validation sample points against the measured values (Proc GLIMMIX, no intercept models with spatial correlation of residuals, SAS 2008). Regressions were considered valid if $P \leq 0.05$ for both sites. Output from validated regression models consisted of 480 values for substrate properties and their spatial coordinates. Spatial analyses of substrate properties were done using GS^+ (Gamma Design Software, Plainwell, MI). Variograms were calculated for each substrate property and contour plots of the covariance surfaces were generated to determine anisotropic patterns (directional dependence) in the data. Ordinary kriging was used to estimate substrate property values across each study site and generate surface maps depicting spatial patterns (Isaaks and Srivastava 1989).

Relationships between substrate properties and stable fly emergence trap collections were evaluated initially with Pearson Correlation coefficients (Proc Corr, SAS 2008). Logistic regression (Proc Genmod, SAS 2008) was used to evaluate relationships between substrate properties and stable fly emergence trap collections. Trap collections were coded as a binary variable indicating presence or absence of emerging flies. Hay ring was considered a categorical variable and substrate property measurements were all considered to be continuous. In the first analysis, stepwise multiple regression ($\alpha = 0.05$) was used to evaluate the relative contribution of each of the substrate properties to the observed variance in emergence trap collections. Properties were removed from the model in a stepwise manner. Spatial autocorrelation of model residuals was evaluated with Moran's I (Proc Variogram, SAS 2008). In the second analysis, substrate properties were evaluated individually to determine 5, 50, and 95 percentile values.

Results

Grid Sampling. Apparent electrical conductivity was low in the center of both sites where the hay feeder had been located (Fig. 1A, B). This low EC_a zone was surrounded by an annular area of higher EC_a representing a zone where hay, urine, and feces were mixed by livestock activity. This zone was asymmetrical with higher EC_a on the eastern side of each site. This asymmetry likely occurred because of cattle congregating on the downwind side of the feeder. Beyond 7 m from the center of each plot, EC_a decreased to background levels. Maximum EC_a values were greater, and the area having EC_a values above 7.5 dS m^{-1} was larger, at site one (Fig. 1A) than at site two (Fig. 1B).

Depth of hay accumulation was greatest in the center of each site where the hay ring had been located (Fig. 1C, D). As distance from the center of the site increased, the depth of hay accumulation decreased. The area of hay accumulation was asymmetrical with greater accumulation and accumulation over slightly greater distances from the center on the eastern side of each site. Hay accumulation depth was 50% less in the center of site one (Fig. 1C) than site two (Fig. 1D).

Substrate temperature was higher in the center of each site than in the surrounding zone of hay accumulation (Fig. 1E, F). Substrate temperature increased in the area beyond where hay had accumulated. Spatial variability in substrate temperature was greater at site one (Fig. 1E) than at site two (Fig. 1F).

ESAP Calibration. Regressions relating EC_a to physical (water content), chemical (EC_{lab}, pH, and total C), and biological (CO_2 emission) substrate properties were significant at both sites (Table 1). The relationship between EC_a and extractable P was not significant at either site while the relationship between EC_a and inorganic N was significant at site one but not at site 2. The estimated values and measured values for the validation samples were similar for water content, EC_{lab}, pH, inorganic N, total C, and microbial respiration rate at both sites (Table 2). There was poor agreement between estimated and measured values for extractable P confirming that there was no relationship between EC_a and this substrate property. Estimated and measured values for total N were related at site one but were not at site 2. Because validation results for total N were inconsistent between the sites spatial patterns in total N were not estimated. None of the residuals exhibited spatial autocorrelation.

Estimated Properties. Variogram models were developed to estimate spatial patterns for substrate properties. For all substrate properties a spherical variogram model provided the best fit ($R^2 > 0.98$). No evidence of anisotropy, which refers to differences in the spatial covariance among samples by orientation, in the covariance plots was observed and thus isotropic models were used.

The physical substrate property estimated was water content. Water content values were low in the center of each site where the hay feeder had been located. Water content increased in an annular region that extended 3–7 m from the edge of the feeder which corresponded to the area of hay accumulation described above. At site 1, the area of highest water content was located east of the hay feeder location and exceeded 2.5 g g^{-1} (Fig. 2A). At site 2, the area having water content exceeding 2.5 g g^{-1} was much larger
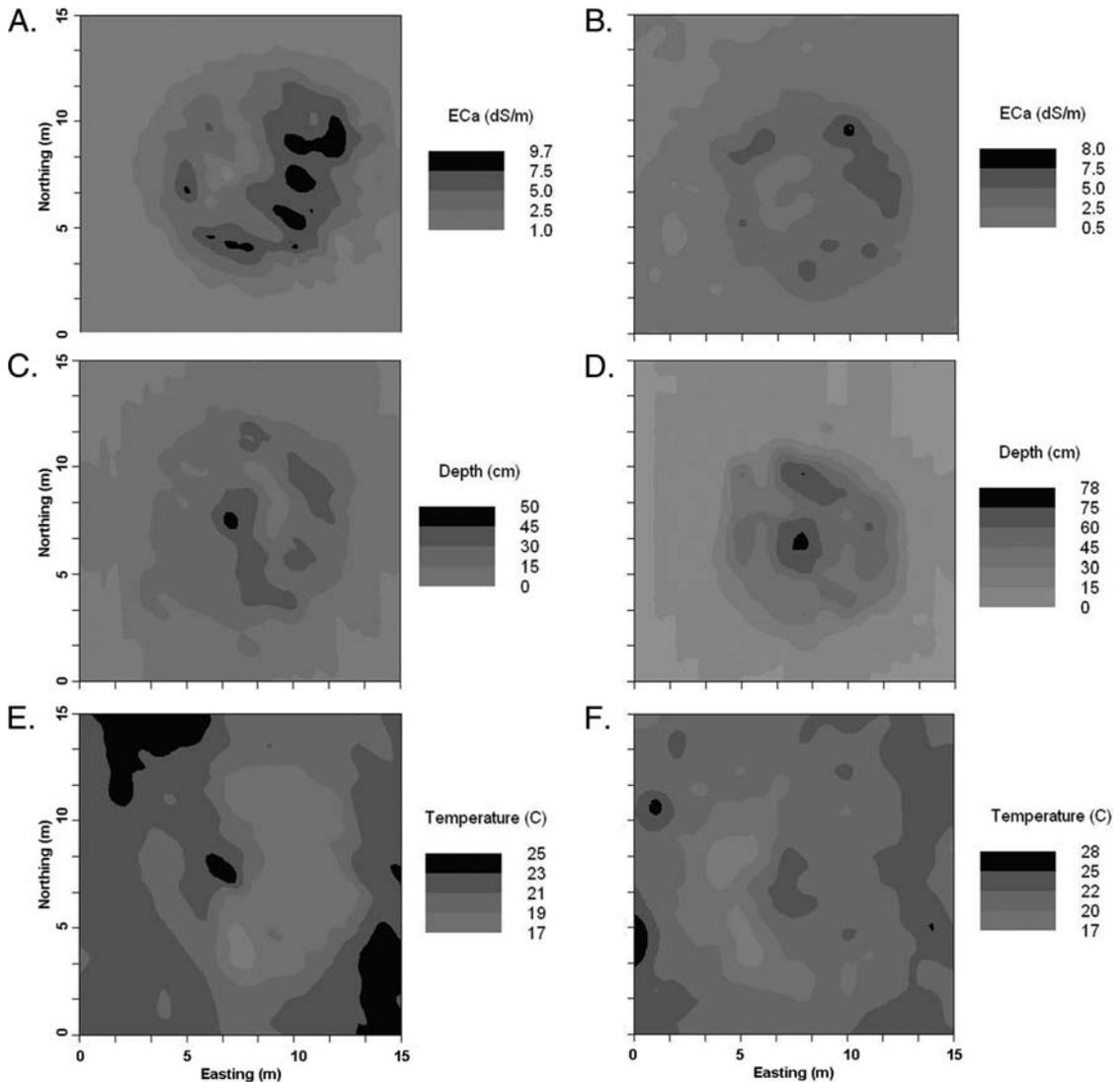
Fig. 1. Spatial pattern for apparent electrical conductivity (A. and B.), depth of substrate (C. and D.), and substrate temperature (E and F) at two round hay bale feeding sites (site one A, C, and E; site two B, D, and F) in eastern Nebraska.

than at site one and extended completely around the feeder location with highest values located east of the feeder (Fig. 3A). Beyond this region water content declined with distance from the feeder at both sites.

Table 1. Coefficient of determination (r^2) and *P* value for relationship between apparent electrical conductivity and substrate properties at two hay ring feeding sites in eastern Nebraska

Substrate property	Site 1		Site 2	
	r^2	*P* value	r^2	*P* value
Water content (g g^{-1})	0.74	0.010	0.80	0.003
Electrical conductivity (dS m^{-1})	0.77	0.006	0.77	0.006
pH	0.74	0.010	0.76	0.008
Extractable P (mg kg^{-1})	0.42	0.205	0.25	0.487
Inorganic N (mg kg^{-1})	0.64	0.035	0.55	0.084
N concn (g kg^{-1})	0.68	0.022	0.69	0.019
C concn (g kg^{-1})	0.67	0.026	0.78	0.005
Respiration rate (mg kg^{-1} hr^{-1})	0.69	0.020	0.83	0.002

The chemical substrate properties estimated were EC_{lab}, pH, NH_4-N, and total C. Values for chemical substrate properties were low in the center of each site where the feeder had been located. At site 1, EC_{lab} increased in an annular area with values exceeding 16 dS m^{-1} in small areas west and south and a larger area east of the feeder location (Fig. 2B). At site 2, the area where EC_{lab} exceeded 16 dS m^{-1} was larger than at site 1, mostly to the east of the feeder location (Fig. 3B). Beyond the area of hay accumulation (Fig. 1C, D), EC_{lab} declined to values found in the surrounding soil. Values for pH were above neutral in the area of hay accumulation and exceeded 7.8 in a small area east of the feeder location at site one (Fig. 2C) and a much larger area surrounding the feeder location at site two (Fig. 3C). Estimated values for NH_4-N were not uniformly distributed around the hay feeder location at

Table 2. Validation results for select substrate properties at two hay ring feeding sites in eastern Nebraska

Substrate property	Site 1			Site 2		
	Coef. $\pm$ SEM	F	P	Coef. $\pm$ SEM	F	P
Water content (g g^{-1})	0.66 $\pm$ 0.10	47.6	<0.01	0.86 $\pm$ 0.12	49.9	<0.01
Electrical conductivity (dS m^{-1})	0.70 $\pm$ 0.09	59.4	<0.01	1.04 $\pm$ 0.17	35.1	<0.01
pH	0.97 $\pm$ 0.02	3029.0	<0.01	0.98 $\pm$ 0.01	7029.1	<0.01
Extractable P (mg kg^{-1})	0.0 $\pm$ 0.02	0.0	0.98	-0.06 $\pm$ 0.13	0.2	0.65
Inorganic N (mg kg^{-1})	0.75 $\pm$ 0.13	35.9	<0.01	0.58 $\pm$ 0.08	55.7	<0.01
N concn (g kg^{-1})	0.64 $\pm$ 0.12	28.4	<0.01	0.28 $\pm$ 0.23	1.6	0.24
C concn (g kg^{-1})	0.68 $\pm$ 0.11	36.9	<0.01	0.54 $\pm$ 0.22	5.9	0.03
Respiration rate (mg kg^{-1} hr^{-1})	1.18 $\pm$ 0.13	79.4	<0.01	0.65 $\pm$ 0.09	57.3	<0.01

Regression of measured and ESAP estimated values.
F and P values are for no intercept models adjusted for spatial correlation of the residuals.
d.f. = 1, 11.

site one (Fig. 2D). Substrate concentration of NH_4-N was >100 mg kg^{-1} in the area of hay accumulation (Fig. 1C) and exceeded 950 mg kg^{-1} in small areas

west and south and a large area east of the hay feeder location. At site 2, NH_4-N concentration was lower than at site one but followed a similar pattern with
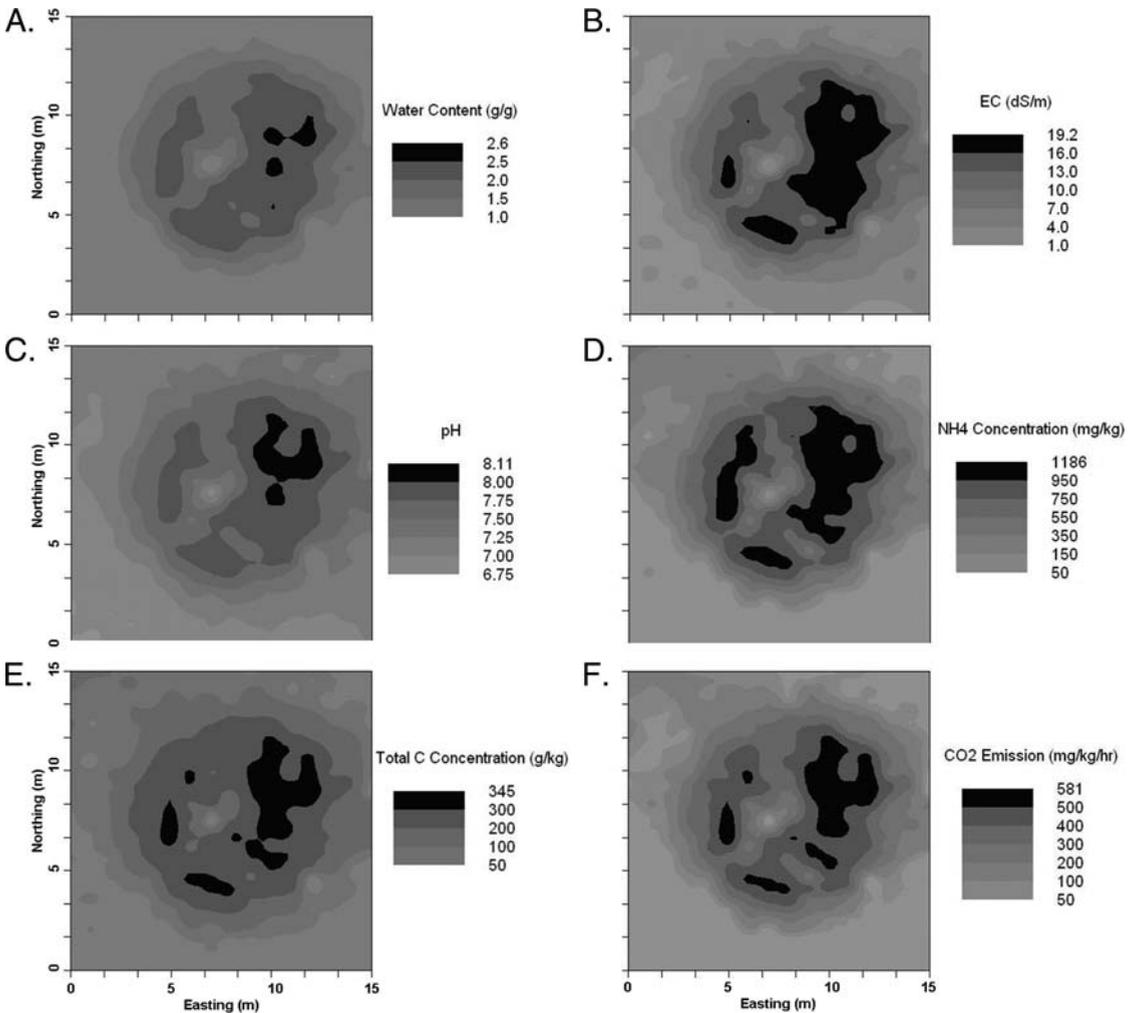

Fig. 2. Spatial pattern for substate water content (A), laboratory electrical conductivity (B), pH (C), ammonium concentration (D), total carbon concentration (E), and microbial respiration (F) and round hay bale feeding site one in eastern Nebraska.
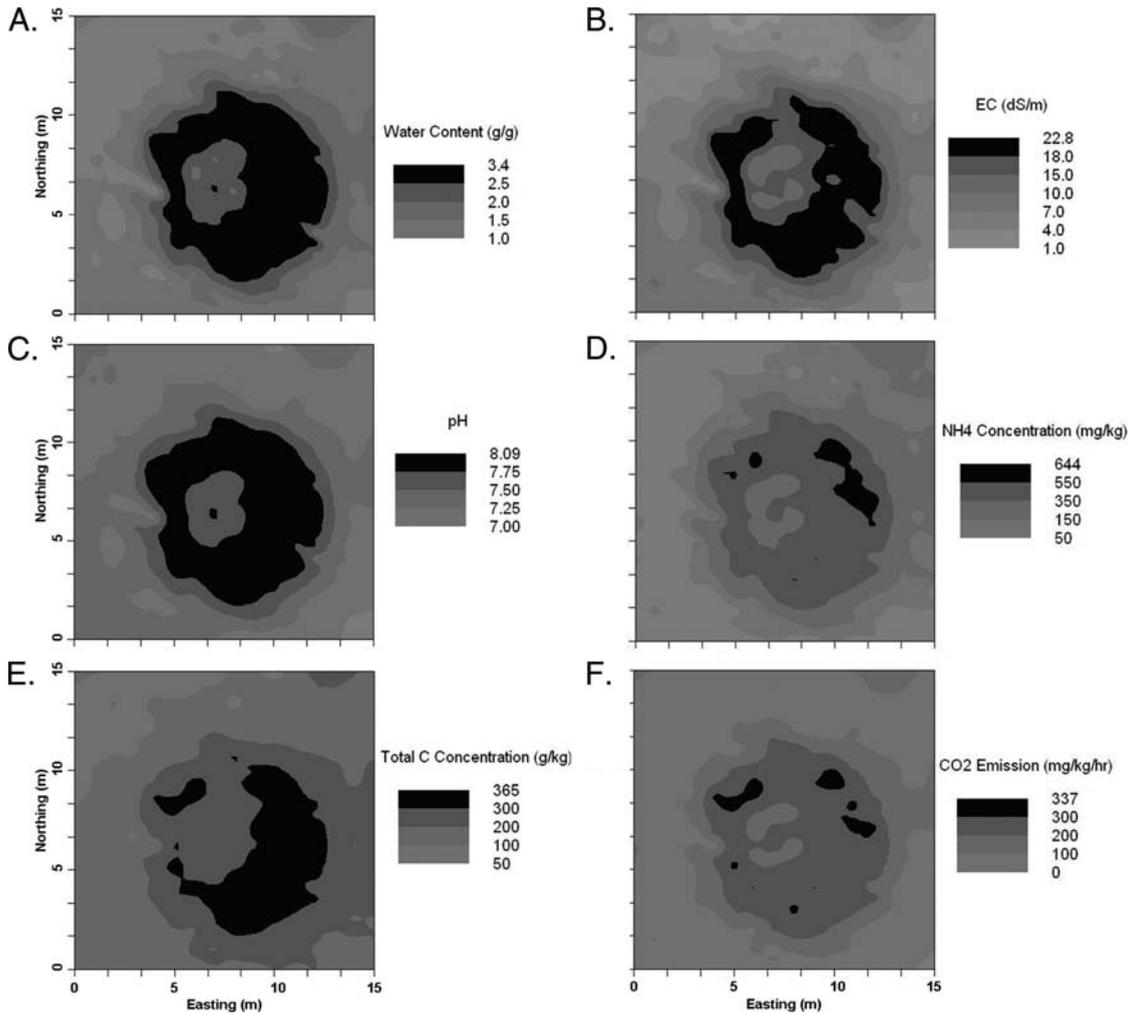
Fig. 3. Spatial pattern for substrate water content (A), laboratory electrical conductivity (B), pH (C), ammonium concentration (D), total carbon concentration (E), and microbial respiration (F) and round hay bale feeding site two in eastern Nebraska.

elevated concentrations in the area of hay accumulation (Fig. 1D) and highest concentrations east of the hay feeder location (Fig. 3D). Total C concentration at site one was between 200 and 300 g kg^{-1} over most of the area of hay accumulation with areas, mainly east of the hay feeder location, exceeding 300 g kg^{-1} (Fig. 2E). At site 2, the pattern in total C concentration was similar to that at site one but the area exceeding 300 g kg^{-1} east of the hay feeder location was greater than at site one (Fig. 3E).

Substrate biological activity was assessed by determining microbial respiration rate. Respiration rates were greatest in an annular area surrounding the hay feeder location with much of the area exhibiting rates >400 mg CO$_2$ kg^{-1} hr^{-1}. At site 1, the largest area of high respiration was east of the feeder location with smaller areas south and west of the feeder. In areas where little or no hay accumulation occurred (Fig. 1C), respiration rate decreased rapidly (Fig. 2F). When compared with site 1,

respiration rates were lower at site 2 (Fig. 3F). At site 2, only a few isolated areas exhibited respiration rates >300 mg CO$_2$ kg^{-1} hr^{-1}.

Adult emergence was estimated to be concentrated in an annular area around where the feeder had been located at both sites. At site 1, greatest emergence is expected in an area east of the hay feeder location and two smaller patches west of the feeder location (Fig. 4A). At site 2, adult emergence was also estimated to be concentrated in two areas northeast and northwest of where the feeder had been located (Fig. 4B).

Six substrate properties, EC$_{lab}$, moisture, pH, total C, NH$_4$, and CO$_2$ were positively correlated with stable fly emergence traps collections (Table 3; Fig. 5). Stepwise logistic regression identified EC$_{lab}$ as the best predictor of collecting one or more emerging stable flies. None of the other properties provided additional predictive information related to emergence (Table 3). The two hay rings did not differ with
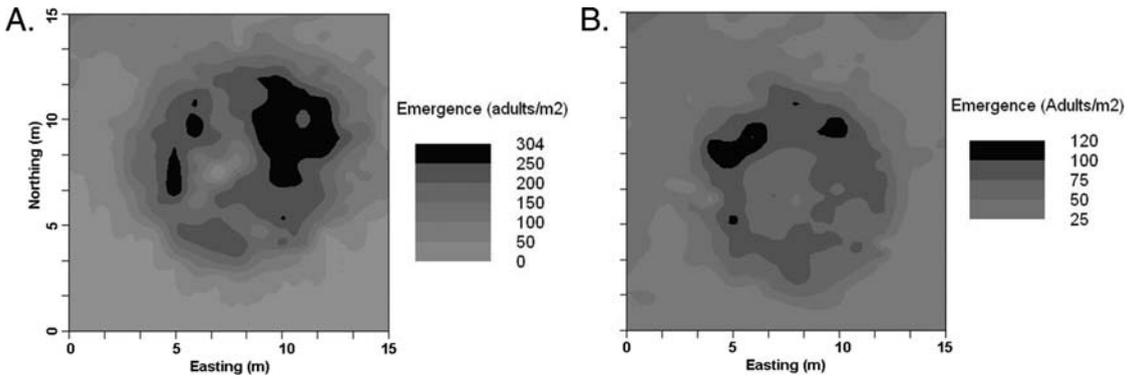
Fig. 4. Spatial pattern in adult stable fly emergence at round hay bale feeding site one (A) and two (B) in eastern Nebraska.

respect to stable fly emergence ($\chi^2 = 1.0$; df = 1; $P = 0.31$) or stable fly emergence relative to EC ($\chi^2 = 0.03$; df = 1; $P = 0.86$). No upper threshold was observed for the six substrate properties, but five percentile values for EC, total C, NH_4, and CO_2 were >5 times larger than the minimum values observed for those properties (Table 3). The fifty percentile value for each property is indicated in Table 3.

Discussion

High levels of spatial variation were observed in the physical, chemical, and biological properties of substrates associated with winter hay feeding sites. This variability likely resulted from the feeding behavior of the cattle as they use the hay feeder as shelter against the prevailing north-westerly wind while feeding. Residue depth and extent of the sites characterized in this study were similar to those described by Broce et al. (2005) in Kansas. The spatial patterns observed in the current study are more complicated than the three concentric zones described by Talley et al. (2009). In that study, zones were delineated visually. Substrate temperature and fecal coliform bacteria levels were similar among zones, water content and substrate depth were greater in

the inner and intermediate zones relative to the outer zone, and pH was lower in the inner and intermediate zones relative to the outer zone. Stable fly emergence rates were similar among the zones, but within zones variation was high (coefficients of variation = 0.25–0.35) indicating the zones were heterogeneous. Evaluation of stable fly emergence rates from areas delineated with the concentric rings model in Nebraska concluded that they were not uniform and did not identify developmental sites reliably (Taylor and Berkebile 2011). In that study, the number of stable flies emerging from the three zones varied, but the pattern was not consistent from site-to-site. The properties characterized in this study provide greater resolution for characterizing spatial variation in stable fly emergence densities from winter hay feeding sites.

In the current study, substrate temperature varied spatially, but was within the range required for stable fly development (Lysyk 1998) at both sites. Similarly, substrate depth exhibited spatial patterns but Taylor and Berkebile (2011) observed that 91% of larvae were within the top 5 cm and none were found below 10 cm. Their findings suggested that a minimal substrate depth is necessary but excessive depth may not improve habitat suitability.

Table 3. Correlation between stable fly emergence collections and substrate properties

Substrate property	Observed range	r	Logistic Models[a]			
			Stepwise[b]	Individual[c]		
			χ^2	χ^2	Percentiles	
					5	50
Electrical conductivity (dS m^{-1})	0.3–28.5	0.59[d]	24.10[d]	24.1[d]	3.7	6.6
Water content (g g^{-1})	0.3–4.1	0.58[d]	0.00	21.3[d]	0.0	1.3
pH	6.5–8.5	0.58[d]	0.02	19.4[d]	4.5	7.4
C concn (g kg^{-1})	3.1–41.6	0.59[d]	0.04	15.4[d]	15.7	18.6
Inorganic N (mg kg^{-1})	0.0–1620.2	0.72[d]	0.23	20.3[d]	38.8	41.8
Respiration rate (mg kg^{-1} hr^{-1})	6.5–784.4	0.81[d]	0.03	22.9[d]	68.8	71.7

Correlation (Pearson r) of substrate property value and total stable fly emergence trap collection. Logistic regression models for individual substrate properties and 5 and 50 percentile values.

[a] df = 1.
[b] Model for electric conductivity alone and for each of the properties when added to that model.
[c] Stable fly emergence relative to individual substrate properties.
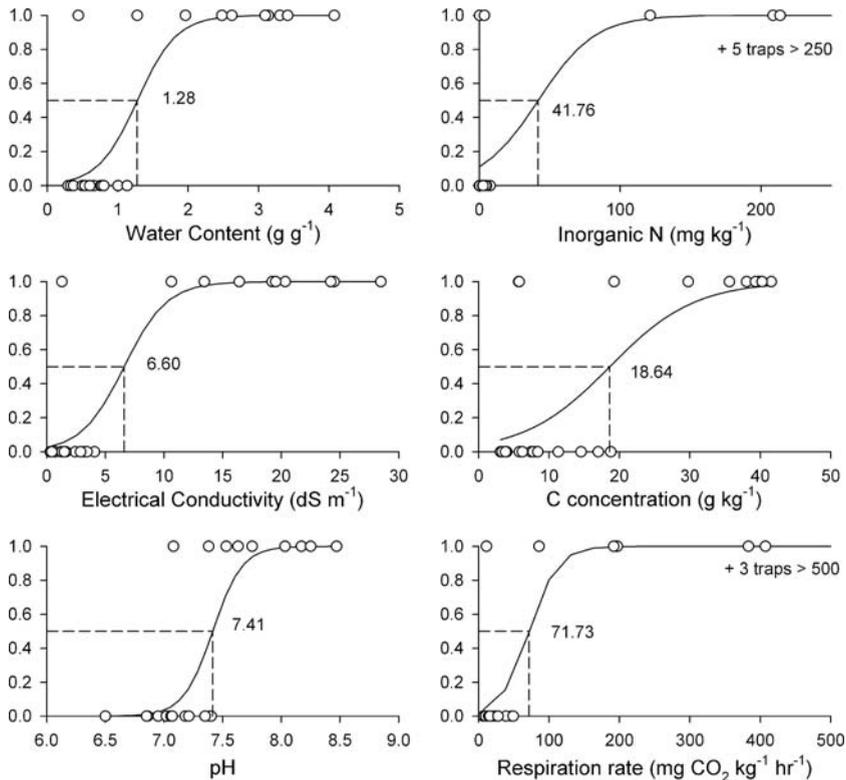[d] $P < 0.05$.

Fig. 5. Logistic regression for finding emerging stable flies as a function of six substrate properties for two hay ring feeder sites in eastern Nebraska.

Substrate properties measured in this study that correlated with stable fly emergence included moisture content, NH_4-N concentration, EC_{lab}, total C concentration, pH, and microbial respiration rate (Table 3; Fig. 5). This is in contrast to results of Broce and Haas (1999) who found no correlation between female stable fly visitation and physiochemical properties of aged feedlot or dairy manure. In the current study, sample points where emergence was observed had higher values for all properties than sample points where no emergence was observed (Fig. 5). Relative to the hay feeding sites characterized by Talley et al. (2009), we observed higher pH values and similar moisture levels. Values for other physical and chemical properties of stable fly round hay bale developmental sites have not been previously documented.

In concordance with previous studies, we found microbial respiration rates to be higher in zones from which adult stable fly emergence was observed. Stable fly larvae cannot develop in substrates deprived of living microbial communities (Romero et al. 2006) and high coliform bacteria levels coincide with seasonal periods of high stable fly emergence (Talley et al. 2009).

Understanding spatial variability in stable fly developmental habitats has a number of practical applications. Sampling strategies that account for spatial variation will be more efficient. Logistic regression results suggests that EC alone can be used to delineate vari-

ation within a habitat and programs like ESAP-95 can be used to identify directed sampling designs. Such designs should reduce sampling effort and variation among samples; provide more accurate estimations of stable fly populations in developmental sites, and assist in site selection for the evaluation of control technologies. Directed sampling designs will also improve detection of biologically active zones within development sites allowing for targeted implementation of management practices. This approach will improve the cost effectiveness of sanitation and chemical treatments for controlling stable flies by reducing labor and treatment area.

Characterized stable fly developmental sites often appear to be inadequate to produce the numbers of adult observed, both temporally and quantitatively (Taylor and Berkebile 2011). The inability to identify local developmental sites has led some to propose long distance movement to account for stable fly populations (Jones et al. 1999). Improved methods for the detection and delineation of stable fly larval developmental sites are needed. Electrical conductivity is highly correlated with several substrate properties and the probability of stable fly emergence from those substrates. In addition, EC can be measured quickly and inexpensively. Combined with directed sampling designs, this technology should help delineate the range of physical, chemical, and biological conditions needed for stable fly larval development which, in

turn, may help in identifying unrecognized habitats and management of this pest.

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