ATMOSPHERIC STABILITY EFFECTS ON PESTICIDE DRIFT FROM AN IRRIGATED ORCHARD

D. R. Miller, T. E. Stoughton, W. E. Steinke, E. W. Huddleston, J. B. Ross

ABSTRACT. Spray transects through an 11-m-tall pecan orchard with an air-blast orchard sprayer were replicated 10 times over a wide range of atmospheric stability conditions. Drift was measured by collecting tracer (malathion) using ground plates (f), high volume air samplers (hv), and string (s) collectors distributed downwind in the adjacent field out to a maximum distance of 18 canopy heights (198 m). Atmospheric conditions were measured above the orchard canopy with fast-response, three-dimensional wind, temperature, and humidity sensors. Atmospheric stability, characterized by the surface layer stability parameter ($\zeta$), was the primary factor affecting drift amounts measured on and above the adjacent field. On average, the total amount of drift caught by the samplers in very stable conditions was 5.9, 3.6, and 2.1 times the amount of drift in unstable conditions for the plates, the hvs, and the strings, respectively. The transition from one condition to the other took place over a very small stability range where the air was dynamically stable ($0.0 < \zeta < 0.3$). In this range, very small changes in atmospheric conditions resulted in very large changes in the atmosphere's aerosol transport characteristics. The effect of stability on the amount of drift collected in the adjacent field is described by a symmetric hyperbolic tangent function over the entire range of stability encountered.

Keywords. Spray drift, Atmospheric stability, Orchard, Airblast sprayer, Pecans, Malathion.

Development of agriculture technology to control spray drift and reduce chemical exposure requires extensive knowledge of the micrometeorological restraints on spray application technologies. This article addresses the interactions of the atmospheric stability and spray drift applied by an orchard air-blast sprayer.

Drift has traditionally been measured by collecting deposit on samplers at various distances downwind from the spray site (Miller, 1993). These measurements have shown a high variability of deposition in time and space (Fox et al., 1998; Bird et al., 1996; Miller et al., 1996). The logistics of spray drift measurement are very difficult and there are only a few studies available, which replicate both spray measurements and sufficient weather parameters over a range of atmospheric conditions.

Bird et al. (1996), Miller (1993), and Bache and Johnstone (1992) provide recent reviews of research on locally measured, average, meteorological effects on drifting spray. The general consensus identifies increased wind speed and intensification of "stable" conditions as important factors in higher drift amounts. The review by Bird et al. (1996) of drift from agricultural aerial spray applications noted the difficulty of comparing previously reported information with recent studies due to an inability to isolate and correct for weather differences, among other problems. They observed that much previous work, Maybank et al. (1978) and Crabbe et al. (1994) for example, generally agrees with the early work of Yates et al. (1967) who found that wind speeds dominate drift deposition amounts in the near field and stability is more important in the far field. In these cases, the "near field" was the downwind distance where droplets large enough to settle out by gravity forces were depositing from a definitive plume; the "far field" was the longer range downwind distances where most of the large droplets were gone and the small droplets remaining in the air were depositing by diffusion and an "undefined" plume.

Bird et al. (1996) summarized current Spray Drift Task Force (SDTF) aerial application studies. They noted that atmospheric stability and wind speed were the only meteorological parameters in the SDTF study that correlated with off-target deposition. Higher wind speeds increased both near and far field ground deposition and increasing stability correlated with higher far field deposition. The SPTF measurements did not include any stable conditions.

The only other meteorological factor, which is frequently cited as responsible for greater drift, is low relative humidity (RH), RH, or the humidity deficit, is the primary controlling parameter in droplet evaporation. This is important to drift because drop size determines how long an aerosol remains suspended in air, as explained in a later section. The relationship between RH and drop size is well known and analytical calculations are readily available (Bache and Johnstone, 1992; Miller, 1993; Kincaid and Longley, 1989). All of the current spray deposition and drift models include evaporation-drop size calculations.
The few ground and orchard sprayer experiments that report stability measurements generally agree with the more extensive aerial spray literature. Fox et al. (1992) measured drift downwind from an apple orchard during low wind speed, unstable conditions. They measured both ground deposit and airborne aerosols and showed no effect of wind speed, but did show higher amounts of material in the air than was deposited in the near field (less than 60 m) and an even higher proportion in the air in the far field (greater than 60 m). MacCollom et al. (1986) measured ground spray drift from an orchard and stated that there was a 20-fold increase up to 150 m away (far field) during periods with an inversion. Bode et al. (1976) noted that wind speed was more important than stability in the unstable to neutral range when drift from ground spray was measured. Phillips and Miller (1999) showed that airborne spray volume in the air from a single stationary nozzle downwind increased linearly with wind speed in the near-field (2 m) during neutral conditions.

Several simulations of spray transport and deposition have been made to estimate the dependence of spray drift on weather factors used in the models. Zhu et al. (1994) use the fluid dynamics model (FLUENT) and calculated increased drift with increased wind speeds up to 200 m away. A constant turbulence intensity typical of unstable conditions was used; therefore variations in stability were not simulated. Teske and Thistle (1999) reported that the aerial spray transport model, FSCBG, estimated significant increases in drift fraction with increasing wind speed for all types of aircraft, again variations in stability were not simulated. Kaul et al. (1996) did simulate the effects of stability. They used a droplet transport model to estimate the influence of changing weather parameters from field sprayers. Their calculation results were for the near field, less than 20 m, and showed little effect of atmospheric stability on ground deposition.

The term “atmospheric stability” includes both “static” stability and “dynamic” stability processes. Static stability refers to the atmosphere’s capability for buoyant convection. If the air is positively buoyant, less dense (warmer and/or wetter) than the surrounding air, it rises; if the air is negatively buoyant, denser than the surrounding air, it subsides. Dynamic stability refers to the effects of wind shear generated (mechanical) turbulence on the static stability condition. High mechanical turbulence causes mixing and reduces the buoyancy effects, whether stable or unstable. Therefore, higher wind speeds act to decrease the intensity of the thermal stability, or instability, by reducing the relative buoyancy and shifting conditions toward neutral. The spray movement and deposition studies cited above define the atmospheric stability by sign and intensity of the local lapse rate using an Richardson number or stability ratio. This “local” definition frequently fails to describe the dominant stability conditions because the rise or descent of air due to density differences depends on the excess buoyancy and not on the local ambient lapse rate (Stull, 1988).

Since the measurement of the local lapse rate alone is not sufficient to determine the static stability, the entire temperature profile through the atmospheric boundary layer or a measurement of the turbulent buoyancy flux should be made (Stull, 1988). Anderson et al. (1992), Miller et al. (1996b), Stoughton et al. (1997), and Miller and Stoughton (2000) used fast response turbulence sensors to measure the turbulent buoyancy flux in and over forest canopies in spray drift experiments and demonstrated the dependence of aerial spray deposition and drift in forests on the stability structure of the atmospheric surface layer. They demonstrated that the mechanisms of spray movement are different in stable and unstable conditions. In an unstable atmosphere, spray movement is dependent on coherent turbulent “events” which last only a few seconds and are on the size scale of the canopy height (Miller et al., 1996b). Whereas in a stable atmosphere, movement is restricted to near ground levels and influenced by the forest edge influence on the wind field (Miller and Stoughton, 2000).

This article specifically addresses the effects of atmospheric stability on the well mixed, far field, drift into an adjacent field from an orchard sprayer. The sprayer, spray operation, and site variables were controlled, while the application and sampling were replicated over a range of atmospheric stability conditions. The static and dynamic stability was measured with fast response turbulence sensors.

METHODS
SITE AND ORCHARD
The site was a flat orchard and field in the Rio Grande valley on the New Mexico State University Experimental Farm, Las Cruces, New Mexico. Figure 1 presents a map of the experimental orchard and adjacent ploughed, bare field with the locations of instrumentation and collectors. The orchard contained mature pecan trees [Carya illinoinensis (Wangenh.) K. Koch] on a 9.14 m (30 ft) square spacing. The average tree height was 11 m, maximum tree height was 14 m with an understory bare space of 2.0 m. There was no ground cover except for occasional clumps of grass. Figure 2 presents the plant area density (PAI) profiles, measured with a LI-COR Inc. LAI-2000 Leaf Area Index Meter using the methods described by Steinke et al. (1996).

SPRAY APPLICATIONS
Spray applications were made with a Wilbur-Ellis airblast sprayer described in table 1, which also lists the spray mix and application rates. Material was applied in a single traverse of the orchard, between the sixth and seventh rows, 62.6 m in from the lee edge. The single traverse (a spray run) took 17 min to complete. Thirty minutes after each spray run was completed, all the samplers were collected and replaced with fresh samplers. The spray runs were replicated 10 times.

SPRAY SAMPLING
Spray was collected in the adjacent bare field (fig. 1) using three different types of samplers at each sampling location. Simultaneous measurements using different types of samplers were made because each is reported to have different collection efficiencies. Data from all three are presented in this article with no effort to compare the efficiencies of different samplers. Readers are referred to a recent study by Bui et al. (1998) for a comparison of their collection characteristics. Flat ground plates (f), 929 cm² area, were used to collect deposition on the ground. Staplex
high volume air samplers (hv) and polyester string webs (s) were mounted vertically, facing the orchard, 1.2 m above the ground to collect airborne drops. The hv samplers were equipped with 62.5 cm² surface area, Gelman type A/E glass fiber filters. Air was drawn at approximately 1 m/s. The string samplers were Conso® 100% polyester cable cord, 0.2 cm diameter and 4 m long. All three types of collectors were co-located in a line at 3H, 6H, 12H, and 18H distance from the orchard edge, where H is tree height (11 m). Additional ground plate samplers were located at 0H, 0.5H, 1H, and 2H from the edge. Five sets of samplers (10 m apart along a line parallel to the orchard edge) were positioned at 3H from the edge. The samplers were placed at distances that were multiples of the orchard canopy height (H) downwind from the edge. Horizontal distances are expressed as x/H because shelter effects downwind from windbreaks (van Eimern, 1964; Brown and Rosenberg, 1970; Miller et al., 1975) and forests edges (Miller et al., 1991) on wind speeds, turbulence, and related transport processes have long been shown to scale with the height of the sheltering canopy.

Samples were immediately recorded and stored in dry ice containers for later shipment and laboratory analysis. Sample analysis was by gas chromatography/mass
sensible heat flux, \( H \), is calculated from \( \sigma_u \sigma_v \sigma_w T \) covariance and \( \langle \rangle \) denotes a time average. The friction velocity, \( u^* \), is calculated as \( u^* = \langle u' \rangle \sqrt{\langle w'^2 \rangle} \), with \( \langle \rangle \) being the mean of the data. The air density, \( \rho \), is 1.205 kg m\(^{-3}\) and \( c_p \), the specific heat at constant pressure, is 1000 J kg\(^{-1}\) K\(^{-1}\). The stability parameter, \( \zeta \), is \( \zeta = (\langle z-d \rangle)/L \) showing where \( z \) is 16 m and \( d \) is the zero plane displacement of the orchard canopy, 7.7 m. L is the Obukov length \( L = \frac{-\rho_c}{\rho \gamma} \) where \( \rho_c \) is the von Karman constant (0.4), and \( g \) is the acceleration due to gravity.

Table 2 presents 30-min average statistics rotated into the mean wind stream, after Kaimal and Finnigan (1994), for each of the spray periods reported in this article. Wind direction is represented by \( U_{dir} \) and was determined before the rotations. Mean wind speed is \( U \). Standard deviations (\( \sigma_u \), \( \sigma_v \), and \( \sigma_w \)) of the streamwise, cross-stream and vertical wind components are

\[
\begin{align*}
\sigma_u &= \langle u'^2 \rangle^{1/2} \\
\sigma_v &= \langle v'^2 \rangle^{1/2} \\
\sigma_w &= \langle w'^2 \rangle^{1/2}
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Stability is measured here by the stability parameter, \( \zeta \), which is a measure of the ratio of thermal turbulence production (k g H) to mechanical turbulence production (\( \rho c_p T u^{-3} \)) at the measurement height (z-d). If the vertical sensible heat flux (H) is upward (positive) due to a warm surface, thermal turbulence is generated due to positive buoyancy and the air is unstable. If H is downward (negative) due to a cold surface, negative buoyancy suppresses turbulence and the air becomes stable. Mechanical turbulence is generated by wind shear, expressed by \( u^* \).

**RESULTS**

**AVERAGE DRIFT RECOVERY**

Figure 3 graphs the average amount of malathion tracer recovered at each downwind measurement site by sampler type. Plate and string data were missing for some runs at 12H; therefore, the values shown in figure 3 are the averages of the measured plate values at 6H and 18H.

Figures 4a-i show the cumulative amount of malathion tracer recovered downwind from the orchard edge in each run by each type of sampler. All the deposition data were reduced to units of ng/cm\(^2\) which is the mass of material collected per unit of cross-sectional area of collector surface. The hv data was corrected to adjust for the lack of isokinesis by the ratio of the wind speed to the intake velocity of the sampler and then divided by the intake cross-sectional area. Ambient wind speeds at each sampler location, during each run were calculated from the wind measurements above the orchard using the tree-stand edge wind field model of Miller et al. (1991). These model estimated wind speeds are listed in table 3.

 Corrections to scale for mean travel distance to the samplers at the different mean wind direction angles encountered were not used. In all the runs, very low wind speeds resulted in high variability of the wind direction (the standard deviation of the wind direction, \( \sigma_\theta \) > 90°) over the 30 min averaging periods. Straight line corrections for meandering, widely mixed, plumes from a time sequenced line source, would likely induce significant errors. The slow transport, high mixing rates, and non-steady direction resulted in mean wind direction values which were only an indication of the general advection direction.

Figures 3 and 4 show that drifting material was collected out to a distance of 18H (198 m) with all three types of samplers in all runs. Also, the run to run variability was quite high. Figure 5 shows averages and standard deviations (\( \sigma_T \)) of the data from figures 4a-i for the plates, high vols, and string samplers, respectively. The graphs demonstrate that all three samplers collected decreasing amounts with distance from the edge but the rates of
The rate of material deposition was highest closer to the orchard edge, as expected. Over 48% of the material collected by the plates, 68% of that collected by the hvs and 59% of that collected by the string was at 3H and 6H (66 m) of the edge. In all cases, some material drifting out of the orchard passed 18H. On average, 7.7% of the material collected by the plates, 9.3% by the hvs, and 21.5% by the string was collected 18H (198 m) from the edge.

The standard deviation values in figure 5 demonstrate that the relative run to run variation remained rather constant with distance from the edge for all three collector types but the relative variation was quite different between the different collector types. The coefficients of variation for each (CV = σ/μ, where μ is the mean and σ is the standard deviation) averaged 0.71 for the flat plates; 0.99 for the hvs, and 0.89 for the strings.

**EFFECTS OF ATMOSPHERIC CONDITIONS**

When all runs were considered together, there was little relationship between wind speed above the orchard and amount of drift collected downwind by the plates and hv samplers in and above the adjacent field (fig. 6). But, when the three very stable runs are removed the expected increase of deposition with higher wind speeds is shown. The strongest increase with increasing wind speed was shown by the strings, likely due to their catch efficiency dependence on wind speed (May and Clifford, 1967). The
relationship between the plates and HV deposition with ambient wind speed was much weaker. The dominance of stability effects over wind speed effects shown in figure 6, was due to the typically low wind speeds encountered and the location of the sampling field in the lee of a tall tree canopy. Estimates of the reduction of wind speed in the lee of the orchard, below that in an unsheltered field, were made using the numerical forest edge model of Miller et al. (1991). The calculations showed reduction in the wind speed at 3H downwind of up to 60% and a reduction of less than 5% at 18H downwind. Apparently the light horizontal winds in these runs (0.9 < U < 3.4 m/s above the orchard) were not sufficient to overcome atmospheric buoyancy forces, which dominated the transport of spray drops, as noted below.

The signs of the stability parameters, ζ, listed in table 2 show that runs 1, 2, 3, 6, 7, and 9 were stable and runs 4, 5, 8, and 10 were unstable. Run 8 was nearest neutral (slightly unstable) due to very low sensible heat flux (H). All three types of collectors amassed higher amounts of material in stable than in unstable conditions. When total sample collected was averaged over runs, the average amount caught by the samplers in dynamically stable conditions, was 1.3, 2.1, and 1.1 times the amount of drift captured in unstable conditions for the plates, hvs and string, respectively. In very stable conditions the total sample collected increased to 5.9, 3.6, and 2.1 times the amount of drift captured in unstable conditions by the plates, hvs, and string, respectively. This same general relationship held for stability effects on the sample amounts collected at any distance from the orchard.

**DISCUSSION**

**STABILITY EFFECTS ON DRIFT.**

Figures 4.1.1a-c shows plots of the deposit, summed for all locations, as a function of atmospheric stability. During unstable conditions (ζ < 0), the amount of material collected decreased only slightly as the intensity of instability increased (ζ → −∞). All three collector types showed this general relationship but the different slopes are probably due to the selectivity of the different samplers for different droplet size distributions.

At first observation, when the stability parameter shows stable conditions (ζ > 0), there appears to be little relationship between the intensity of the static stability and the amount of material collected. But, in fact, the data demonstrate that the transport of the spray aerosols across the adjacent field was quite sensitive to the state of the flow turbulence as controlled by the stability. Theoretical and laboratory research suggests that turbulent flow becomes laminar when the air is stable enough to prevent the generation of mechanical turbulence. This turbulence termination condition exists when a critical value of ζ ≈ 0.25 is surpassed. (Stull, 1988; Woods, 1969; Nieuwstadt and Tennekes, 1981). All of the stable runs were conducted during late afternoon and evening periods when turbulent air flow was being suppressed to laminar. When the data are split into two sets where ζ < 0.3 and ζ > 0.3 there were only two occasions (runs 7 and 9) where the static stability
was high enough ($\zeta > 0.3$) to suppress all the mechanical turbulence. The deposits in these runs remained at the same high level as that near the critical stability value.

Figure 7a-c show a pattern of low, relatively constant, deposit during convective atmospheres until conditions approach neutral. At this point deposit increases very rapidly as the atmosphere becomes slightly stable and approaches the critical value. Then, once the airflow is laminar, the deposit remains high and relatively constant.

To describe this pattern of low deposition in unstable conditions, the rapid increase of deposition with decreasing dynamic stability ($0 < \zeta < 0.3$) and high deposition in very stable, laminar conditions, shown in figure 7a-c, a symmetrical, hyperbolic tangent relationship was fit to the data:

$$D(\zeta) = a + b \left\{ \tan h \left[ c (\zeta - 0.1) \right] + 1 \right\}$$

(1)

where $D(\zeta)$ is the predicted deposit; $a$ is the minimum deposit; $b$ is the range variable ($b \approx 1/3$ the maximum deposit); and $c$ is the slope at the curve center. In these cases $c = 10$ provided the best fit of the data. The parameter “$a$” was 10, 10, and 5; “$b$” was 20, 275 and 45 and “$c$” was 10, 10, 10 for the plates, hv’s and string, respectively.

Figures 8 a-d show the effects of stability on hv deposit at various distances downwind from the edge. At all distances the same pattern persisted, as represented by the hyperbolic equation. But the deposit amounts decreased with distance from the orchard even during intense stability. Thus demonstrating that the material was still dispersing. Most likely the dispersion was horizontal (called fanning in stable conditions) since vertical turbulence was suppressed. The fitting parameters, $a$ and $b$, in equation 1 decrease with distance from the edge (fig. 9).

The pattern of data in figures 7 and 8, described by equation 1, demonstrate that the near surface drift and ground deposit is small across the adjacent field during statically unstable and convective atmospheres. It remains small as the atmosphere becomes less convective until a neutral condition is reached. As the air becomes dynamically stable ($\zeta \rightarrow +$) the amount of drifting material transported near the ground increases rapidly to $\zeta \approx +0.3$, when the mechanical turbulence is suppressed. At intense
static stability above $\zeta = +0.3$, the deposition remained high.

Apparently, when conditions were very stable, airborne droplets didn’t disperse vertically and high concentrations moved horizontally near the ground. Whereas, in the unstable atmosphere, most spray droplets that remained in the air likely mixed upward from the orchard and therefore were not collected in large amounts near the ground surface in the adjacent field.

The transition from one condition to the other took place over a very small stability range where the air was dynamically stable. In this range, very small changes in atmospheric conditions resulted in very large changes in the atmosphere’s aerosol transport characteristics.

DROPLET SIZE AND DISPERSION

Calculations of droplet evaporation after Elliott and Wilson (1983) as cited in Miller (1996), were used to estimate the size of the droplets reaching the adjacent field in this study. The very low relative humidities (< 20%) in this desert environment, combined with the low transport wind speeds in the study, resulted in nearly complete evaporation of the water fraction in the drifting drops. The calculations indicated that almost no droplet sprayed (i.e., < 350 $\mu$m) was larger than about 30 $\mu$m when it reached the first samplers at the downwind edge of the orchard and most were in the range of 0 to 10 $\mu$m with the water fraction essentially gone. Therefore, all the spray reaching the field could not settle out by gravity forces alone. Walklate (1992) showed the same results with a random-walk dispersion model applied to pesticide drift from an orchard sprayer, where the effect of evaporation quickly reduced the size of the airborne droplets to a point where they were all equally well suspended by atmospheric turbulence at 50 m from the sprayer.

The small droplets and long drift times in this experiment resulted in “far-field” dispersion conditions. In other words, the aerosols from the sequential line spray source located 60 m inside the orchard were transported through turbulent air in and over the canopy, mixing completely enough that no coherent plume existed. Thus explaining the small wind speed effect. This wide dispersion is also the reason that travel distance corrections for $\pm45^\circ$ differences in mean wind direction could not be made. The suspended aerosols were likely evenly mixed crosswind, downwind from the orchard, by the short term fluctuations in turbulent air structures associated with the leeward edge of the tall orchard. Therefore, the general direction of advection and short term fluctuations in wind direction are likely better measures of drifting material movement that mean wind direction averaged over 30 min.

Although most of the material sprayed was contained in droplets large enough to catch in the canopy or settle out on the ground in the orchard, an unknown percentage was in droplet sizes small enough to remain suspended and disperse in the air. Of these dispersing aerosols, some were delivered to the surface by turbulent transport processes, but most tended to remain airborne. It is likely that the large amount of material which moved horizontally into the adjacent field in stable conditions, also left the orchard in convective conditions but moved upward. To our knowledge, no experiment has reported data where mass balance calculations from deposition measurements have accounted for more than 70 to 80% of the material sprayed. Fox et al. (1998) summarized the available studies for orchards and noted that about 30% of spray applied was unaccounted for after summing foliage deposition, ground deposition and drift measurements. This unaccounted fraction has generally been attributed to inadequate spatial and temporal sampling and undersampling of the smaller droplets by passive samplers. These results indicate the possibility that a significant proportion of the unaccounted for material may be dispersed upward into the atmospheric boundary layer.

SOME IMPLICATIONS FOR SPRAY DRIFT MANAGEMENT

The range of atmospheric wind and stability conditions encountered in this study are reasonably typical for afternoon and evening spray operations in pecan orchards in the New Mexico desert. The time of spraying was between early afternoon and dusk, and the conditions changed from unstable to dynamically stable as soon as the sun angle was low enough to no longer heat the ground surface inside the orchard. Thus, the risk of exposure of adjacent fields to concentrations of spray material increased by a factor of 2 to 6 in the evening hours over the afternoons. It is interesting to note that during two weeks of continuous measurement in this experiment the stability parameter, $\zeta$, was in the dynamically stable range between 0.0 and +0.3 about 80% of the time at night. During these times drift amounts could be anywhere over the entire range measured because very small changes of heat flux, wind or turbulence results in very large changes in drift deposition.

Only two “very stable” runs were available; therefore extrapolation of these results to night periods when $\zeta \geq +0.3$ is tenuous. But, the consistently high deposits during these runs indicates that the large amounts of drift near the surface across the adjacent field can be expected in very stable conditions because the vertical turbulent dispersion mechanism has been completely suppressed.

CONCLUSIONS

Most of the spray material drifting out of the orchard into the adjacent field deposited, or dispersed upward, within 6H of the orchard edge. But some material drifted further 18H (198 m) in each run.

Atmospheric stability was the major determinant of deposition amount in the adjacent field. Only very low wind speeds were encountered in this study, therefore wind speed by itself had only a small effect on the amount or pattern of drift. On average, the total amount of drift caught by the samplers in very stable conditions was 5.9, 3.6, and 2.1 times the amount of drift in unstable conditions for the plates, the hvs, and the string, respectively. The transition from one condition to the other took place over a very small stability range where the air was dynamically stable (0.0 < $\zeta$ < 0.3). In this range, very small changes in atmospheric conditions resulted in very large changes in the atmosphere’s aerosol transport characteristics.

In this range, when the atmosphere was dynamically stable, the amounts of drift collected increased rapidly as the stability suppression of mechanical turbulence increased. Overall, the effect of stability on the amount of drift collected in the adjacent field can be reasonably
described by a symmetric hyperbolic tangent function over the entire range of stability encountered. The sample amounts collected from all three types of samplers were highly correlated run to run confirming that the dominant effect of stability was real and not a sampling artifact.

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REFERENCES


