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Does particulate matter along roadsides interfere with plant reproduction? A comparison of effects of different road types on *Cichorium intybus* pollen deposition and germination[☆]

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ABSTRACT

The roadside habitat can be challenging for plants, which must maintain normal biological processes despite an influx of airborne pollutants. While the effects of many gases on plants have been quantified, the impacts of particulate pollutants have been relatively less studied. This is especially true of field experiments where particle dispersion may be influenced by meteorology and roadway use. We examined chicory (*Cichorium intybus* L.) along roadsides in the Cincinnati, Ohio metropolitan area to assess particulate influence on plant pollination through stigmatic clogging. We compared flowers collected from plants situated along interstates, U.S. highways, state highways, and county roads as these different road-types vary in motor vehicle usage and thus should have varying levels of particulate deposition on flowers. We examined floral stigmas for total particulates, total pollen, and percentage of pollen tube germination to determine whether particulates may interfere with early reproductive processes. Our results suggest that there was minimal variation of particulate matter found on chicory stigmas among road-types. Furthermore, the deposition of particulates on stigmas based on road-type did not show a strong link to variation in pollen deposition and pollen germination. There was also no significant relationship between total particulate levels and pollen germination rates across all road types. Future studies should investigate other plant species that may be more sensitive to roadside pollution, such as economically important crops. Locations in which vehicle use is increasing and where pollutants are not regulated strictly should also be examined as the effects of airborne particulates in early plant reproduction would be expected to be more substantial in these areas.

1. Introduction

As the use of motor vehicles increases worldwide and especially in developing nations where air pollution is less monitored, understanding the effects of vehicle emissions on air quality is becoming increasingly important. Historically, air pollutants produced from industry and automobiles were considered the most harmful to both humans and plants - these pollutants often consisted of coal smoke and production of gases such as carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxides (NO_x). Because these gases are now more closely monitored, there is a shift in focus to other potentially damaging airborne pollutants, such as particulate matter (PM). PM is also produced in part by industrial and vehicular activity and has known negative health effects on humans, ranging from eye irritation and respiratory problems to neurological ailments, and even lung cancer (de Andrade et al., 2011; Ohio Environmental Council, 2004). Because of these detrimental human health effects, air pollution, and in particular PM, has become a ubiquitous national and global concern. Consequently, research has now begun to focus on secondary effects of PM on vegetation and crops.

Exhaust from vehicles is one of the principal anthropogenic sources of airborne PM (Rai et al., 2010). Vehicular particulates are produced by incomplete fuel combustion, which creates a carbonaceous material that absorbs surrounding compounds (both

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organic and inorganic) and then condenses (Sarvi et al., 2011). The use of vehicles on roadways not only produces PM by way of car and truck exhaust but also leads to localized dusts on road surfaces becoming airborne while driving (Farmer, 1993). PM may also become airborne near motorways due to wear on vehicles including tire abrasion, brake linings and clutch plates (Thompson et al., 1984).

Meteorology can have a strong effect on atmospheric PM distribution. In general, this is based on particle size and composition. For example, larger, heavier PM is less likely to travel as far as smaller particulates and will also settle more quickly. Furthermore, surrounding meterological conditions such as temperature, air density, wind speed, and wind angle also influence where particles are deposited (Liang, 2014). Weather patterns can influence spatial and temporal variations in PM dispersion, thus changing where PM accumulates on flora. Factors such as traffic flow and the presence of multiple traffic lanes on a road can also play a role in local wind patterns (Eskridge and Rao, 1983; Liang, 2014). Furthermore, air turbulence from roadway traffic and even car idling can also have an effect on particle distribution.

Living along roadsides and lacking voluntary locomotion, plants are highly susceptible to anthropogenic activity in their vicinity, including motorway exhaust and PM. Specifically, plants of economic (crops) and natural value are constantly bombarded with roadway pollutants in many areas. Although the effects of pollutant gases on plants have been heavily examined (e.g., Honour et al., 2009; Saxe, 1983a, 1983b), the effects of PM from roadways are less well demonstrated in the field despite the potential of particulates to negatively impact crucial plant functions such as reproduction. Some known effects of PM on plant reproduction include a delay in flowering time in some species treated with daily doses of urban dust (Rai et al., 2010). Delayed flowering and lower rates of flowering were also observed in fumigation studies in which herbaceous plants were exposed to an urban roadside pollutant mixture (Honour et al., 2009). Reductions in fruit production were also observed in a variety of annual plant species following urban dust treatments (Rai et al., 2010). Air pollution including PM can also have detrimental effects on pollen, potentially leading to pollen inviability and other harmful consequences. For example, pollen collected from *Lagerstroemia indica* L. in highly polluted areas include smaller, misshapen and delicate pollen grains, with finer exine coatings along with decreased overall pollen production and in some cases, exocytosis (Rezanejad et al., 2003). Pollen subjected to high pollutant levels was also coated with greater quantities of PM (Rezanejad et al., 2003).

In this study, we examine chicory (*Cichorium intybus* L.) inflorescences collected along different types of roadways to estimate the impact of motorway PM on early reproductive processes. To do so, we examined pollen deposition by quantifying the ability of PM to bind to floral stigmas and thus potentially hinder the natural adherence of pollen and interfere with pollen germination. Ultimately, this would reduce seed production and limit reproductive output in roadside populations. We hypothesized that larger, more heavily used roads would incur higher amounts of PM on chicory stigmas, resulting in relatively lower counts of viable pollen and rates of pollen germination than samples collected along less well traveled roads.

2. Materials and methods

2.1. Location

Sampling took place in the greater Cincinnati, Ohio area during Summer 2012. During June and July 2012 when field sampling was conducted, the average temperature of this area was 25 °C with 9.58 cm of cumulative rainfall. Four road-types of varying levels of traffic usage were selected based on the Ohio Kentucky Indiana Regional Council (OKI): (1) interstate, (2) U.S. highways, (3) state highways and (4) county roads. Annualized average daily traffic (AADT) counts were collected by OKI near each of the sampling sites. The average AADT across the four replicates within each road-type were 121,533 vehicles for interstates, 24,718 vehicles for U.S. highways, 13,843 vehicles for state highways, and 8,873 vehicles for county roads. Within the Cincinnati area, four geographic locations (A-D) were chosen as replicates, each containing all of the four road-types (1–4) for a total of 16 sampling sites (Fig. 1). Each sampling site is referred to by its geographic location and road-type (e.g. A1 for geographic location A, interstate; Table 1; Fig. 1). Sampling sites of each road-type within a geographic location were located within a 5-km radius to minimize localized meteorological variations.

2.2. Study species

In this study, we examined chicory (*Cichorium intybus* L.), a herbaceous and weedy plant (Fig. 2) that is common along roadways, especially in industrial areas.

Chicory is also used in food production, often as a sweetener or coffee substitute (Aksoy, 2008). Although it is native to Europe, West Asia, and North Africa, it has become naturalized throughout the U.S. including the Midwest region, making it a good choice for this study. Furthermore, it has been used as a phytoindicator in other pollution studies (e.g. Misik et al., 2006). Chicory was also chosen based on its flowering time during summer months. Each chicory flower (technically a composite head of florets, but referred to here as a flower) blooms for only a single day; therefore flowers that were collected while open in the field had only been exposed to roadway exhaust for a single day. Ideal for this study, chicory will continue to bloom for several days if stems are collected from the

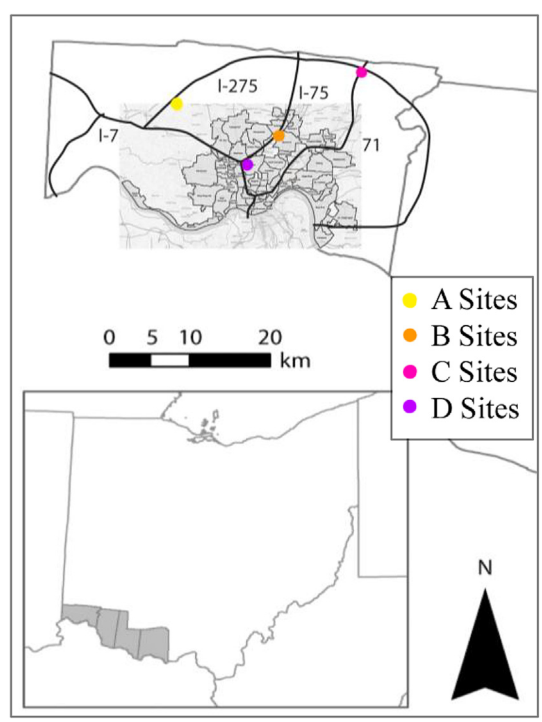

Fig. 1. Map of Ohio (lower) with the major roadways surrounding the greater Cincinnati region (upper) shown. The four sampling geographic locations are labeled in the greater Cincinnati region.