Establishment and persistence of common ragweed (*Ambrosia artemisiifolia* L.) in disturbed soil as a function of an urban-rural macro-environment

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Running Title: Ragweed persistence as a function of urbanization.

Key Words. Annual plants, Carbon dioxide, Ragweed, Soil disturbance, Urbanization.

Abstract.

No data are available on whether rising carbon dioxide concentration [CO_2] or increased air temperature can alter the establishment and persistence of common ragweed (*Ambrosia artemisiifolia* L.) within a plant community following soil disturbance. To determine ragweed longevity, we exposed disturbed soil with a common seed bank population to an *in situ* temperature and [CO_2] gradient along an urban-rural transect beginning in early 2002. No other consistent differences in meteorological variables (e.g. wind speed, humidity, PAR, tropospheric ozone) as a function of urbanization were documented over the course of the study (2002-2005). Above-ground measurements of biomass over this period demonstrated that ragweed along the transect responded to urban induced increases in [CO_2]/temperature with peak biomass being observed at this location by the end of 2003. However, by the Fall of 2004, and continuing through 2005, urban ragweed populations had dwindled to a few plants. The temporal decline in ragweed populations was not associated with increased disease, herbivory or auto-allelopathy, but was part of a demographic reduction in the total number of annual plant species observed for the urban location. In a separate experiment, we showed that such a demographic shift is consistent with CO_2/temperature induced increases in biomass and litter accumulation, with a subsequent reduction in germination / survival of annual plant species. Overall, these data indicate that [CO_2]/temperature differences associated with urbanization may increase initial ragweed productivity and pollen production, but suggest that long-term, multi-year persistence of ragweed in the urban macro-environment may be dependent on other factors.

Introduction.

Common ragweed (*Ambrosia artemisiifolia* L.) is considered a serious or troublesome weed in crop systems in both the Eastern and Southeastern United States (Bridges 1992). In addition, the genus *Ambrosia* has long been recognized as a significant cause of allergic rhinitis, with an estimated 10% of the U.S. population (32 million) considered ragweed sensitive (Gergen et al. 1987).

The impact of ragweed on human systems has led to numerous investigative efforts to describe or model its growth and floral capacity by both botanists and health care providers (e.g. Emberlin 1994, Deen et al. 1998, 2001, Frenz 2000). It is recognized that ragweed establishment, as with many annual pioneer or weedy species, requires both soil disturbance (usually anthropogenic, e.g. discing of a field), and a specific soil environment (e.g. temperatures above 5ºC)(e.g. Shrestha et al. 1999).

Beginning in February of 2002, we established a series of edaphically homogenous experimental plots at each of three sites along an urban-rural gradient differing in [CO_2] and temperature as a means to study the impact of climate change on the dynamics of secondary succession of fallow agricultural soil. Such an approach provided a unique opportunity to also examine how urbanization might alter specific annual weeds, such as ragweed, by quantifying temporal changes in plant number, biomass and pollen production following soil disturbance. Previous work had established that ragweed monocultures placed along this same urban-rural gradient could show a significant annual stimulation in growth and pollen production in response to urban induced changes in [CO_2], temperature and growing season length (Ziska et al. 2003).

While intriguing, these earlier data did not address the establishment and longevity of ragweed within mixed plant communities as a function of these same parameters (CO_2, temperature). Overall, little is known regarding the persistence of ragweed populations following a disturbance; even though longevity of ragweed is an obvious factor with respect to its pollen and seed production over time. Our objective therefore, was to quantify multi-year ragweed persistence as a function of urban-rural macro-climates following soil disturbance and, if possible, to suggest a mechanistic / ecological basis for any temporal changes in ragweed populations.

Materials and Methods.

Site location. Three sites had been selected along a CO_2/temperature transect that had been used in a previous study and where the microclimate had been partially characterized (Ziska et al., 2003). These sites are located at an organic farm near Buckeystown, Maryland (control site) approximately 50 km from the center of the city of Baltimore; a city park (Carrie Murray Nature Center, suburban site) that is on the edge of the city/county line, approximately 10 km from the city center and a site at the Baltimore Science Center (urban site) that is <0.5 km from the city center. All sites are surrounded by mowed grass, or an alfalfa/orchard grass mixture (organic farm) that is periodically harvested, and sources of external seed are minimal.

Plot Establishment. Fallow soil was initiated by discing in the summer of 2001. Beginning in late February of 2002, the top 20 cm of this soil (with its viable seed bank) was removed from the Beltsville experimental farm over a 6 x 9 m area. The soil had not received any pesticide applications for at least five years. Soil sampling determined that this was a Cordurus silt-loam with pH 5.5 and high availability of potash, phosphate and nitrate (*Cordurus hatboro*). Soil was bulked, then sieved to remove rhizomes, stolons and corms. This was done to ensure that only seed was contained within the soil and that regrowth from below ground structures did not confound germination and emergence from the seed bank. Following bulking, the soil was mixed uniformly and subsamples of the soil were placed in 20 x 30cm flats in sunlit greenhouses to evaluate the seed bank. Germination from these subsamples indicated uniform mixing and the presence of approximately 40 annual and perennial species including common ragweed and several tree species. Remaining soil within the 6 x 9 m area (primarily B and C horizons, from 20 to 110 cm) was then evacuated by backhoe, mixed and set aside. For each site along the transect described above, four 2 x 2 m plots were excavated to a depth of ~1.1m with the soil removed. The lower horizons (i.e. the soil obtained from the Beltsville site from 20-110 cm) were added to each plot and tamped to obtain a uniform bulk density. Following placement of the lower layers, the seed bank soil was added to the top 20 cm of each plot. Plots were randomly placed at each site and were not shaded by surrounding structures. To minimize border effects, shade cloth which has been specially designed to simulate leaf spectral properties (EZ Gardener, Waco, TX) was placed around each plot, and raised to canopy height as the plants grew.

Weather Stations. Weather stations (Campbell Scientific, Logan UT), were installed at all sites along the transect. A boxed enclosure (ENC) containing a datalogger (CR10x) was mounted on a tripod (CM6) and connected to an anemometer (03001), an air temperature and humidity probe (CS500), a soil temperature probe (CS 107) at a depth of 15 cm, a 6 plate radiation shield (41301 RM), a rain gauge (TE 525), an infrared CO_2 analyzer (S151, Quibit Systems, Ontario, Canada) and a quantum sensor (LI190SB, Li-Cor Corporation, Lincoln, NE). In addition, a US weather bureau, class A evaporation pan was placed at each site.

Each weather station was powered by a 12-V direct current deep-cycle marine battery that was recharged by a 10-W solar panel (MSX10R, Campbell). All environmental parameters were recorded at 5-minute intervals and downloaded weekly through use of a storage module (SM192, Campbell) and keypad (CR10KD, Campbell). All instruments were factory calibrated. CO_2 analyzers were re-calibrated monthly for each site. Since water stress was not a treatment effect, plots at each site were hand-watered (tap water) as needed to match estimates of evapo-transpiration as determined from meteorological values and pan evaporation (e.g. Table 3, Ziska et al. 2004). Soil moisture was measured continuously at each site using Echo probes (Decagon, Pullman, WA) beginning in 2004. Probes were placed horizontally at a depth of 10cm. A Calibration curve derived from the original field soil placed in each plot was used to calculate site specific soil moisture.

Other Meteorological Variables. To ensure that other variables influenced by urbanization did not affect plant growth, data from EPA sites for ozone collection (near to the urban and rural locations only) were assessed to determine daily concentrations (8 h ozone averages) and potential location differences from May through September from 2002-2005.   Since tropospheric ozone formation can vary spatially, passive samplers for ozone determination were also established at each location along the transect in 2004 (Bytnerowicz et al. 2001). Both the EPA data and *in situ* collection indicated no consistent daily (or seasonal) differences between rural and urban locations during the growing season (Figure 1).

In addition to ozone, nitrate deposition from airborne pollutants has been found to be higher in urban relative to rural areas (Lovett and Rueth 1999).   Nitrogen limited plants could benefit from the fertilizer effect of nitrogen deposition to increase growth and carbon assimilation rates. Beginning at the end of 2003, passive samplers (Bytnerowicz et al. 2001) were also used to determine atmospheric nitric acid vapor (HNO_3) concentrations along the transect. Average weekly dry deposition of NO_3 was slightly, (but not significantly) higher for the urban relative to the rural location with a difference of about 200 μg m^2. Measurements of nitrate and nitrite in rainwater using high performance liquid chromatography to achieve separation (NO_3) and colorimetry with sulfanilamide (NO_2) indicated a slightly higher increase in N deposition for the urban area as well (urban-rural differences of 0.4μm and 3.3nm for NO_3 and NO_2, respectively).

Estimation of pollen production. Monocultures of ragweed had been monitored previously along the same transect in 2000 and 2001 (i.e. similar gradient of temperature and [CO_2], see Ziska et al. 2003) prior to initiation of the current study. During this period, pollen was quantified for these monocultures using

Rotorod samplers (Model 20; Sampling Technologies, St. Louis Park, MN) installed at 1.5 m above grade in circular arrays around each population (Raynor et al. 1970). Atmospheric samples were obtained on an intermittent (modified 10% duty cycle) but synchronous basis with retracting heads and duty cycle timers (Sampling Technologies, St. Louis Park, MN). Collector rods were prepared and processed under standardized conditions by a single analyst (Frenz and Guthrie 2001). Resulting pollen data were converted to volumetric equivalents (pollen grains per cubic meter of air) and aggregated for each sampling period by site. All samplers were calibrated at the beginning and end of the 2000 and 2001 growing season to ensure proper performance (Frenz and Elander 1996). The relationship between the mature dry weight of individual ragweed plants from seven monocultures of ragweed (approximately 20 plants per monoculture) over a two year period and pollen collected from these plants was used to establish a simple linear relationship (r^2 =0.91). This relationship was used to estimate pollen release from the changes in ragweed biomass observed during the 2002-2005 period in this study

Sampling and Assessment of Biomass. During emergence in April and through early May, circular rings (0.5 m^2) were placed randomly within each plot and numbers of each species, including ragweed, determined. Growing season was considered as the number of frost-free days between Spring and Fall. Destructive harvests at each site did not occur until the last frost (Fall) and subsequent mortality of the plot. Following plot mortality, ragweed was identified, cut at ground level and separated. Herbaceous annuals and perennials were also identified although deterioration of a few species did not allow identification. Allometric relationships between height or diameter were used to estimate the biomass of any perennial woody species. All plant biomass was dried until a constant weight was obtained, then weighed. Following weighing, biomass was re-distributed to each plot. Four plots at each site served as replicates for that transect location. Plant biomass at the end of the growing season and estimated pollen production were analyzed using a one-way analysis of variance (Statview, SAS, Cary, NC), to determine the effect of location macro-climate.

Litter deposition and Seed Germination. In 2004, the top 20 cm of soil from an adjacent location near the original seed bank site at Beltsville, Maryland was bulked, mixed and placed in tubs (24 x 37 x 15 cm) in greenhouses. Initial germination tests indicated that this soil contained the same seed bank as the original soil source for the urban-rural transect. To determine the influence of litter deposition on seed germination, dried litter of the same species (e.g. lambsquarters, ragweed) that had been observed after the first year of the transect experiment, was placed at three different densities on each of four tubs. The three densities (1.96, 3.05 and 4.23 kg m^{-2}) corresponded to the total biomass production from each of the three transect sites after the first field season of the current study (see Ziska et al. 2004). Following litter deposition, germination of all annual species (e.g. ragweed) was determined over a 5 week period. At the end of this period, the entire experiment was repeated. Seedling counts were then tabulated and the impact of litter deposition on annual seed germination determined using a one-way analysis of variance (Statview, SAS, Cary, NC).

Results.

Urbanization impacts on macro-climate. Among environmental parameters, consistent year to year differences in both [CO_2], air temperature and growing season length were observed from 2002-2005 for the urban relative to the rural location (Table 1). These differences, whether for air temperature or [CO_2], were consistent throughout the experiment (e.g. August of 2004, Figure 2). Other meteorological variables, wind speed, PAR, or VPD did not differ consistently between locations (data not shown). Although ozone values were high relative to accepted standards of the US Environmental Protection Agency, (www.epa.gov/air/oaqps/cleanair.html), the ozone levels reported here are representative of large areas of eastern North America (Krupa and Manning 1988, Krupa and Kickert 1997) and did not differ daily or seasonally between rural and urban locations (e.g. Figure 1). The small but consistently greater amount of dry and wet N deposition for the urban site could, potentially, result in greater fertilization of urban areas, but all seasonal sources of N per m^2 were less than 0.1% of the amount of N already present in these high nitrogen agronomic soils; hence, the degree of difference between locations seems unlikely to alter growth responses for the period of the current study.

Establishment, biomass and pollen production of common ragweed. Seedling counts of ragweed taken in the Spring of 2002, indicated uniform establishment of ragweed at all sites along the transect (Figure 3). Although initial numbers did not vary, by the Fall of 2002, ragweed above-ground biomass was significantly greater at both the urban and suburban sites relative to the rural site (Figure 4). This was observed again in 2003, with the urban site showing an average ragweed biomass of approximately 200 gm^{-2}. However, by Spring of 2004, and continuing in the Spring of 2005, ragweed populations had approached zero at the urban site (Figure 3), and no significant biomass was observed for this location after the Fall of 2004 (Figure 4). In contrast, by the Fall of 2004 suburban biomass increased to levels approaching that of the urban site the previous year and peaked by the Fall of 2005; while consistent increases in ragweed biomass were observed for the rural location from 2002-2005 (Figure 4). Estimated changes in pollen production reflect changes in above ground biomass for this same period (Figure 5).

Discussion.

It is worth noting that the data presented here indicate that the two principal environmental parameters expected to increase with climatic change, ambient air temperature and [CO_2], also increase as a function of urbanization. In addition, a longer growing season, as has been projected with some global climate scenarios (Fitter and Fitter 2002), also occurs with urbanization (Ziska et al. 2004). These data reinforce earlier observations that urban or city environs are already subject to the kind of environments that are projected for the next 50 to 75 years for the planet as a whole (e.g. Idso et al. 1998, 2001, Ziska et al. 2001).

Although exploiting an existing CO_2/temperature urban-rural gradient to examine ragweed populations does not allow separation (or control) of [CO_2] and temperature effects, it is reasonable to anticipate an empirical link between future increases in [CO_2] and the occurrence of increased air temperature. In any case, a differential biological response to an existing urban-rural macro-climatic gradient will have contemporary ecological implications, especially for plants that exploit anthropogenic disturbance such as common ragweed.

In the current experiment, initial ragweed growth and pollen production within the plant community was greater in an urban, relative to a rural, environment. Macro-meteorological differences associated with the urban-rural gradient indicated no consistent differences in humidity, wind speed, direction, PAR, or ozone for any year of the experiment (see also Ziska et al. 2003, Ziska et al. 2004). In addition, the observed productivity increases with urbanization were not associated with greater initial emergence of ragweed (e.g. Figure 3). This suggests that the stimulation of initial ragweed biomass and pollen output may be related to the higher [CO_2] and temperature values, as well as the longer growing season associated with urbanization. Such a suggestion would be consistent with previous data indicating

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a strong response of individual ragweed plants and ragweed monocultures to increased [CO_2] and temperature (Wan et al. 2002, Ziska and Caulfield 2000, Ziska et al. 2003).

Since both [CO_2] and temperature are increasing concurrently in this macro-environment, their respective impact on ragweed growth and phenology is difficult to assess. Regression analysis during 2002 comparing productivity along the transect to meteorological factors indicated that both increased temperature and [CO_2] contribute significantly to productivity (Ziska et al. 2004). Each factor, in turn, may contribute to such biological events as catkin production, flowering, pollen release, etc. that are specific to ragweed (Ziska et al. 2003).

Interestingly, for the current experiment, a restricted assessment of only the 2002/2003 data would suggest a strong influence of rising [CO_2] and/or temperature on ragweed growth in an urban setting (with subsequent effects regarding pollen output). However, as the current results also make clear, sustained ragweed productivity at the urban site did not occur following the initial disturbance; rather, in 2004 and 2005, common ragweed was all but eliminated at that location, even though productivity had been high initially.

Why is the persistence of ragweed in the urban setting short-lived, particularly since urban environments appear to favor ragweed growth? Visual inspection indicated no increased disease or insect vectors specific for ragweed at the urban location. Because areas surrounding plots at each location were maintained as either mowed grass or alfalfa and did not contain ragweed, stochastic population fluctuations seem unlikely. On the other hand, a build-up of ragweed at a given site could be associated with increasing auto-allelopathy (e.g. alfalfa) with a subsequent decline in species number; however, seedling counts of ragweed for the suburban site were still high in May of 2005 (Figure 3) even after achieving a similar biomass to the urban site in the Fall of 2004.

It is worth noting that the decline in ragweed populations for the urban site was observed for other annual plants as well. Overall, while significant increases in biomass productivity were observed initially with the warmer temperatures and higher CO_2 concentrations associated with urbanization (Ziska et al. 2004), by the Fall of 2004, numbers of all annual species (not just ragweed) had declined for the urban (relative to the rural) plots. This suggested a possible link between increased biomass productivity and the temporal success of annual species.

How would such a link be expressed? One possibility is that increased productivity is associated with greater litter deposition. Litter deposition in turn, would reduce light interception at the soil surface. The light requirements for annual seed germination and establishment are well-documented (cf Wesson and Wareing 1969, Noronha et al. 1997). Alternatively, given the small size of many annual seeds, (with limited carbohydrate resources), increased litter could limit light interception and result in seedling death once germination occurred.

To test this possibility, seed germination of annual species was quantified using different litter densities corresponding to the observed initial changes in biomass production for each site along the urban-rural transect (Figure 6). These data are consistent with the hypothesis that litter accumulation may have decreased annual (e.g. ragweed) seed germination / emergence with a subsequent decrease in the population of annual species (e.g. Figure 3). If the extent of biomass stimulation is related to the degree of urbanization (i.e. increased temperatures and/or CO_2 increase with urbanization see Ziska et al. 2004), then the litter accumulation hypothesis would also suggest that suburban ragweed populations would peak and decline next, followed by rural populations. This is consistent with the observed data for ragweed biomass through the end of 2005 (Figure 4). It could be argued that the higher urban temperatures would result in a greater decomposition of litter as well; however, the over-winter (Nov. to Feb.) average temperatures from 2003-2005 were approximately 4 and 7ºC for the rural and urban locations, respectively. In addition, the large amounts of initial above-ground biomass and the more than double increase in litter at the urban relative to the rural site (Ziska et al. 2004), combined with the cold temperatures, suggest that decomposition *per se* would not have eliminated differences in litter accumulation as a function of urbanization by the following Spring. Certainly, there was no visual evidence of this.

But if greater litter accumulation results in less ragweed over time in an urban location following soil disturbance, how can we account for the ubiquitous appearance of ragweed in cities? Given the dependence of ragweed on soil disturbance, it seems likely that differential rates of disturbance may also be a critical factor in determining the persistence of ragweed populations as a function of urbanization. Although empirically, one might anticipate greater soil disturbance related to human activity in urban and suburban areas, to our knowledge, the degree of disturbance has not been quantified.

Given its influence on human systems, particularly public health, it is of obvious importance to understand ragweed biology, particularly establishment, longevity, growth and pollen output. The current study confirms previous findings that ragweed can show a strong growth and pollen response to climatic variables likely to change in the future (e.g. Ziska and Caulfield 2000, Wayne et al. 2002), but also begins to elucidate the degree of complexity regarding the persistence and longevity of ragweed in mixed populations with concomitant increases in carbon dioxide and temperature. As such, it provides a unique understanding of the temporal and spatial scales needed to understand ragweed biology in the context of urban and global change.

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References cited.

Bridges DC (1992) *Crop Losses Due to Weeds in the United States*. Weed Science Society of America, Champaign, IL, USA, pp 1-30.

Bytnerowicz A, Padgett P, Arbaugh M, Parker D, Jones D (2001) Passive samplers for measurement of atmospheric nitric acid vapor and ozone concentrations. *The Scientific World* **1**, 1-8.

Deen W, Hunt T, Swanton CJ (1998) Influence of temperature, photoperiod, and irradiance on the phenological development of common ragweed (*Ambrosia artemissiifolia*). *Weed Science* **46**, 555-560.

Deen W, Swanton CJ, Hunt LA (2001) A mechanistic growth and development model of common ragweed. *Weed Science* **49**, 723-731.

Emberlin J (1994) The effects of patterns in climate and pollen abundance on allergy. *Allergy* **49**, 15-20.

Fitter AH, Fitter RSR (2002) Rapid changes in flowering time in British plants. *Science* **296**, 1689-1691.

Frenz DA (2000) Interpreting atmospheric pollen counts for use in clinical allergy: spatial variability. *Annals of Allergy, Asthma and Immunology* **84**, 481-491.

Frenz DA, Elander JS (1996) A calibration program for Rotorod Samplers. *Annals of Allergy, Asthma and Immunology* **76**, 245-246.

Frenz DA, Guthrie BL (2001) A rapid, reproducible method for coating Rotorod Sampler collector rods with silicon grease. *Annals of Allergy, Asthma and Immunology* **87**, 390-393.

Gergen PJ, Turkeltaub PC, Kovar MD (1987) The prevalence of allergic skin test reactivity to eight common aeroallergens in the US population: results form the second National Health and Nutrition Examination survey. *Journal of Allergy Clinical Immunology* **80**, 669-679.

Idso CD, Idso SB, Balling Jr. RC (1998) The urban CO_2 dome of Phoenix, Arizona. *Physical Geography* **19**, 95-108.

Idso CD, Idso SB, Balling Jr. RC (2001) An intensive two-week study of an urban CO_2 dome in Phoenix Arizona, USA. *Atmosphere and Environment* **35**, 995-1000.

Krupa SV, Manning WJ (1988) Atmospheric ozone: formation and effects on vegetation. *Environmental Pollution* **50**, 101-137.

Krupa SV, Kickert RN (1997) Considerations for establishing relationships between ambient ozone (O_3) and adverse crop response. *Environment Review* **5**, 55-77.

Lovett GM, Rueth H (1999) Soil nitrogen transformations in beech and maple stands along a nitrogen deposition gradient. *Ecological Applications* **9**, 1330-1344.

Noronha A, Andersson L, Milber P (1997) Rate of change in dormancy level and light requirement in weed seeds during stratification. *Annals of Botany* **80**, 795-801.

Raynor GS, Hayes JV, Ogden ED (1970) Experimental data on ragweed pollen dispersion and deposition from point and area sources. *BNL Publication #50224.* Brookhaven National Labs, Upton NY.

Shrestha A, Roman ES, Thomas AG, Swanton CJ (1999) Modeling germination and shoot-radical elongation of *Ambrosia artemisiifolia*. *Weed Science* **47**, 557-562.

Wan S, Yuan T, Bowdish S, Wallace L, Russell SD, Luo L. 2002. Response of an allergenic species, *Ambrosia psilostachya* (Asteracea), to experimental warming and clipping: implications for public health. *American Journal of Botany* **89**, 1843-1846.

Wayne P, Foster S, Connolly J, Bazzaz F, Epstein P (2002) Production of allergenic pollen by ragweed (*Ambrosia artemisiifolia* L.) is increased in CO_2-enriched atmospheres. *Annals of Allergy, Asthma and Immunology* **88**, 279-282.

Wesson G, Wareing PF (1969) The induction of light sensitivity in weeds seeds by burial. *Journal of Experimental Botany* **20**, 414-425.

Ziska LH, Caulfield FA (2000) Rising CO_2 and pollen production of common ragweed (*Ambrosia artemisiifolia*), a known allergy-inducing species: implications for public health. *Australian Journal of Plant Physiology* **27**, 893-898.

Ziska LH, Ghannoum O, Baker JT, Conroy J, Bunce JA, Kobayashi K, Okada M (2001) A global perspective of ground level, ‘ambient’ carbon dioxide for assessing the response of plants to atmospheric CO_2. *Global Change Biology* **7**, 1-8.

Ziska LH, Gebhard DE, Frenz DA, Faulkner SS, Singer BD, Straka JG (2003) Cities as harbingers of climate change: Common ragweed, urbanization, and public health. *Journal of Allergy and Clinical Immunology* **111**, 290-295.

Ziska LH, Bunce JA, Goins EW (2004) Characterization of an urban-rural CO_2/temperature gradient and associated changes in initial plant productivity during secondary succession. *Oecologia* **139**, 454-458.

Table 1. Yearly averages of day-time CO_2 concentration and day (D) and night (N) temperatures by year at a height of 1.5m along an urban-rural transect. No consistent differences were observed for photosynthetically active radiation (PAR), wind speed, or VPD over this same period as a function of urbanization (data not shown, but see Table 2, Ziska et al. 2003 and Table 1, Ziska et al. 2004). Data are from April until October 1st. CO_2 and temperature are in μmol mol^{-1} and ºC, respectively. While the suburban location did not have a longer growing season (i.e. number of frost free days) than the rural location, the urban growing season exceeded the rural location by 36, 41, 52 and 39 days from 2002-2005, respectively. Day to day variation in air temperature and [CO_2] is shown in figure 2 for selected months in 2004.

Location	2002			2003			2004			2005		
	CO_2	D Temp.	N Temp.	CO_2	D. Temp.	N Temp.	CO_2	D. Temp.	N. Temp.	CO_2	D. Temp.	N. Temp.
Rural	385	24.5	12.9	393	22.6	18.0	401	24.4	19.0	402	25.3	19.0
Suburban	401	25.9	13.1	405	23.9	18.6	414	24.7	18.7	436	26.0	19.3
Urban	466	26.4	16.3	516	24.7	21.3	489	26.4	22.1	478	27.2	22.7

Figure Legends.

Figure 1. Daily 8-h tropospheric ozone values (nl O_3 l^{-1} of air) for both the rural (open circles) and urban (closed circles) locations for the 2004 season. Ozone data were obtained from EPA monitoring stations and checked against dry deposition rates on filters (Bytnerowicz et al. 2001). Overall, no significant differences in ozone were observed between the urban and rural sites for any year (2002-2005) of the experiment.

Figure 2. Daily average daytime differences in carbon dioxide concentration (μmol mol^{-1}) and air temperature (°C) between the urban and rural locations for May and August 2004. Overall, urbanization resulted in consistent, significant increases in both parameters relative to the rural site during the growing season from 2002-2005 (See Also Table 1).

Figure 3. Seedling counts observed in May averaged for all plots at each location for the urban-rural transect from 2002-2005. Bars are ±SE. * indicated a significant reduction relative to the rural location for a given date (t-test, assuming unequal variances).

Figure 4. Ragweed biomass at the end of each season averaged for all plots at each location for the urban-rural transect. Bars are ±SE. Lines are “best-fit” secondary regressions. The last year the soil was fallow (2001) is also included. * indicates a significant increase in ragweed biomass relative to the rural control site (t-test, assuming unequal variances).

Figure 5. Using the biomass estimate shown in figure 4, a previously established regression analysis for these locations (Ziska et al. 2003) was used to estimate ragweed pollen production for the years 2002-2005.

Figure 6. Change in the germination of total annual plant species as a function of litter deposition. (Specific values for ragweed were 267, 145 and 86 per m^2 with increasing litter deposition). The amount of litter added was based on observed changes in initial annual plant productivity for this transect; i.e. litter deposition increased as a function of urbanization. (see Ziska et al. 2004).

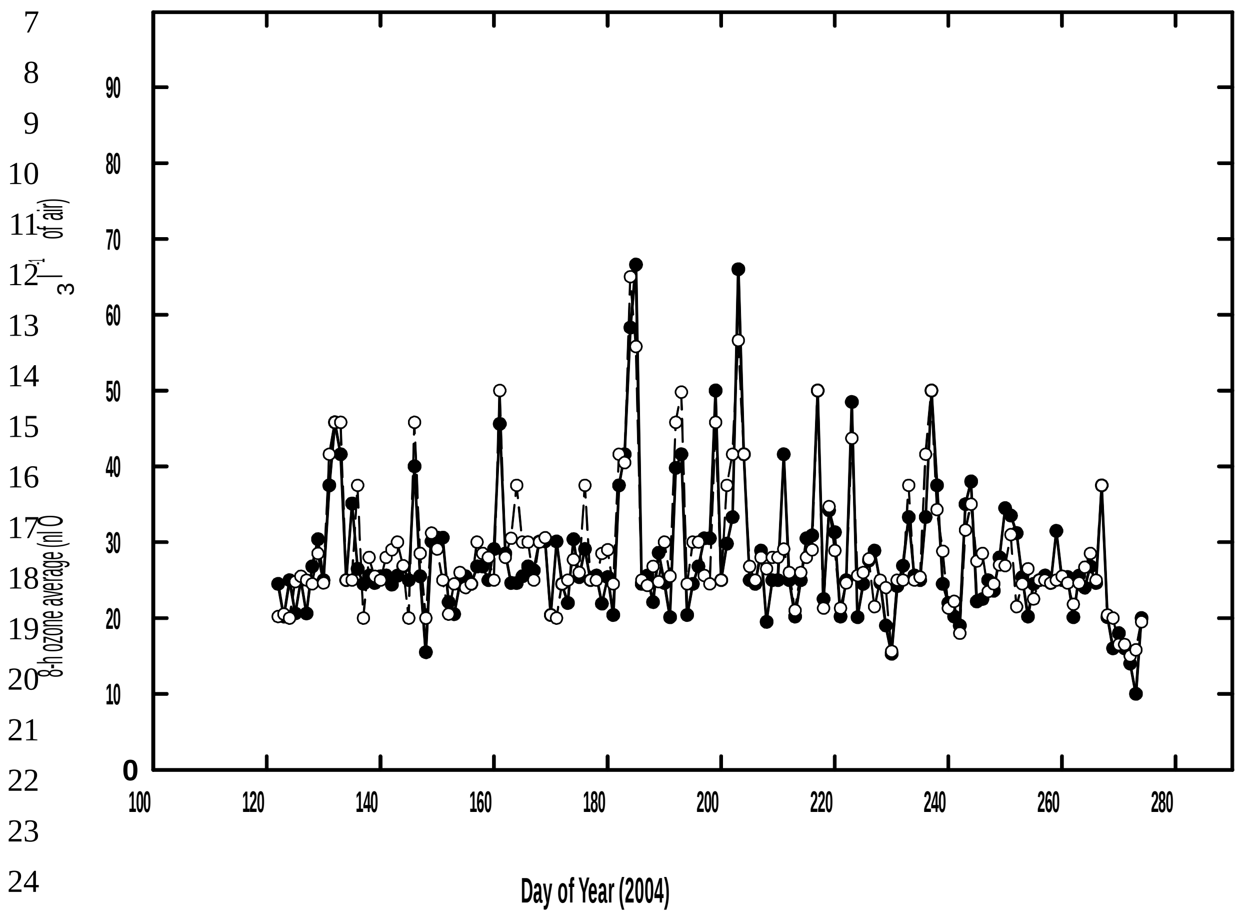
90
80
70
60
50
40
30
20
10
0
100
120
140
160
180
200
220
240
260
280
Day of Year (2004)
8-h ozone average (nl O
3
of air)

Figure 1

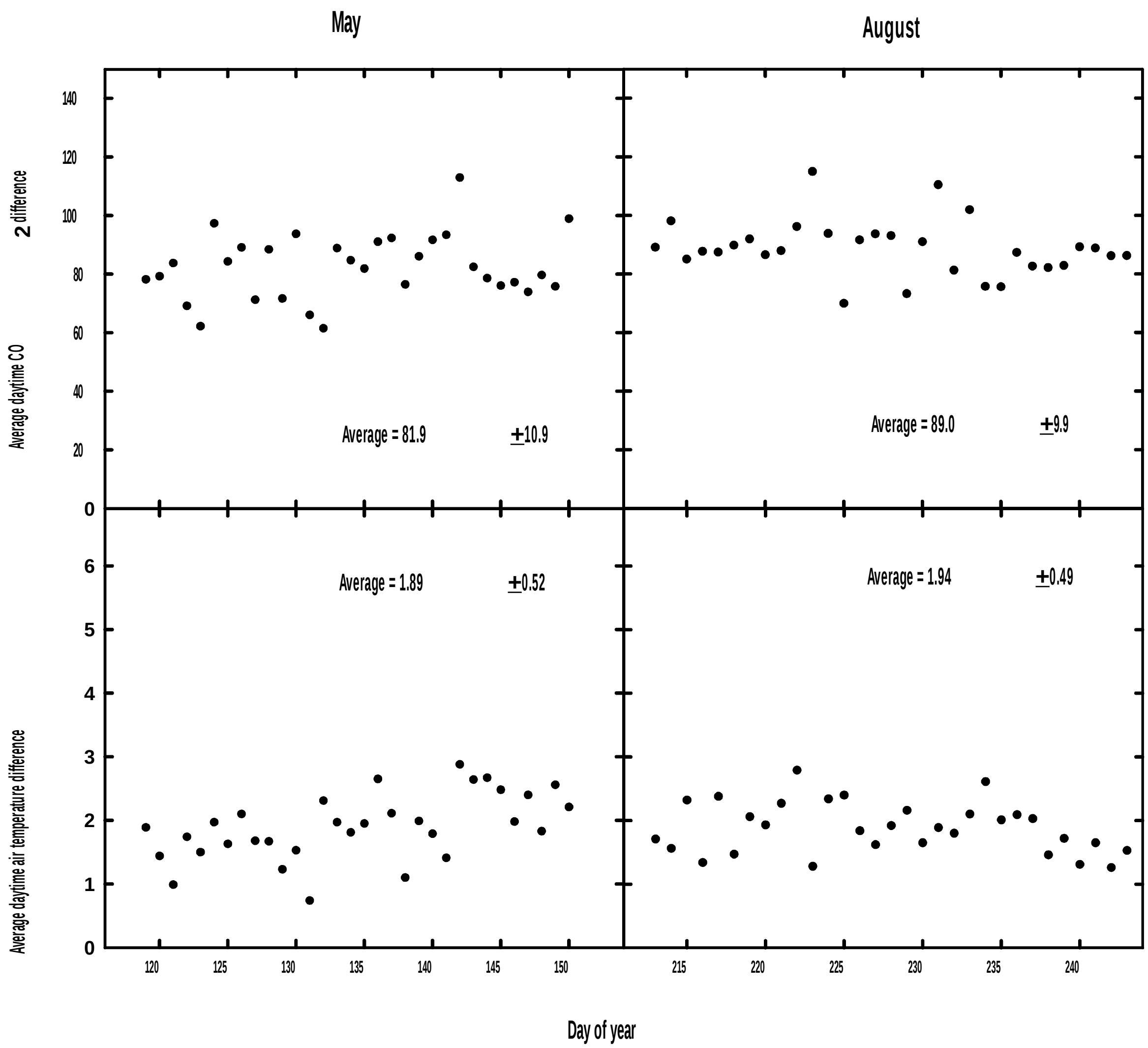
May
August
Average daytime CO 2 difference
Average = 81.9 ±10.9
Average = 89.0 ±9.9
Average = 1.89 ±0.52
Average = 1.94 ±0.49
Average daytime air temperature difference
Day of year

Figure 2

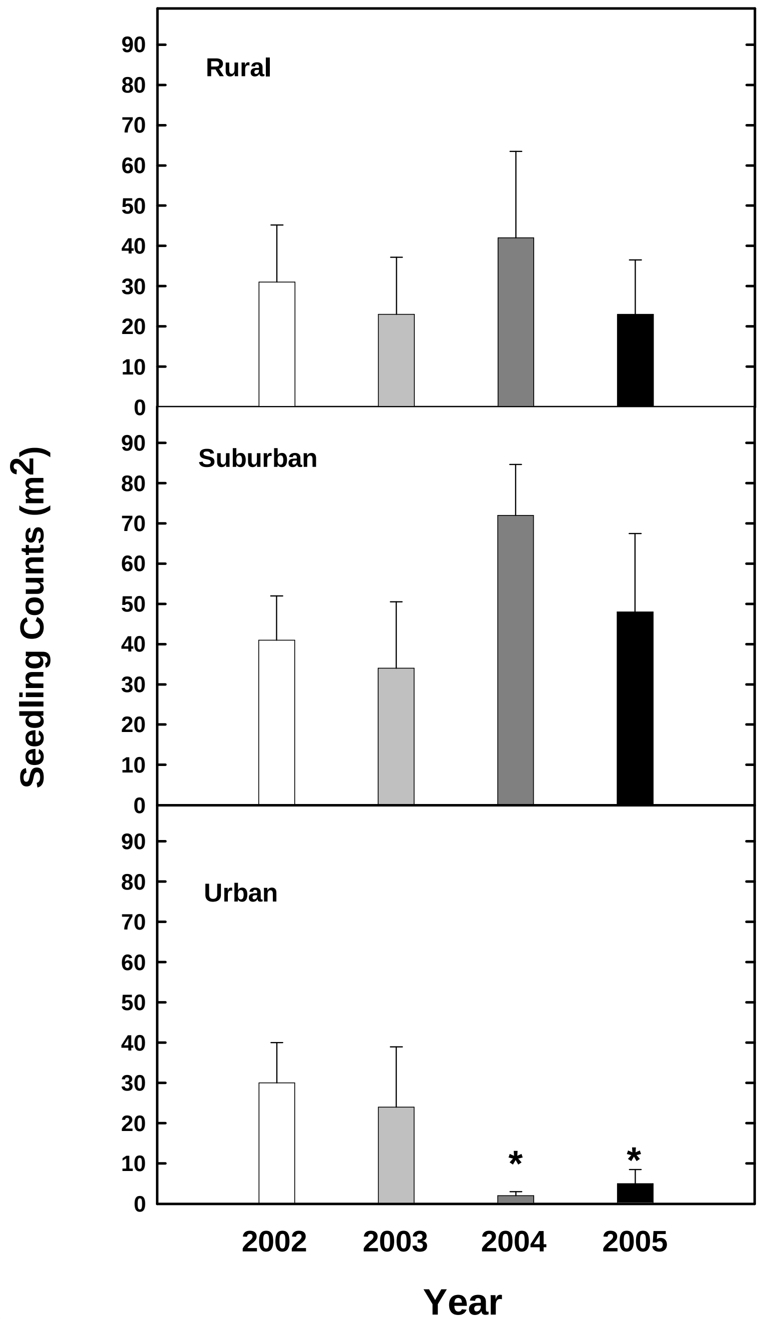
Rural
Suburban
Urban
Seedling Counts (m2)
0
10
20
30
40
50
60
70
80
90
2002
2003
2004
2005
Year

Figure 3

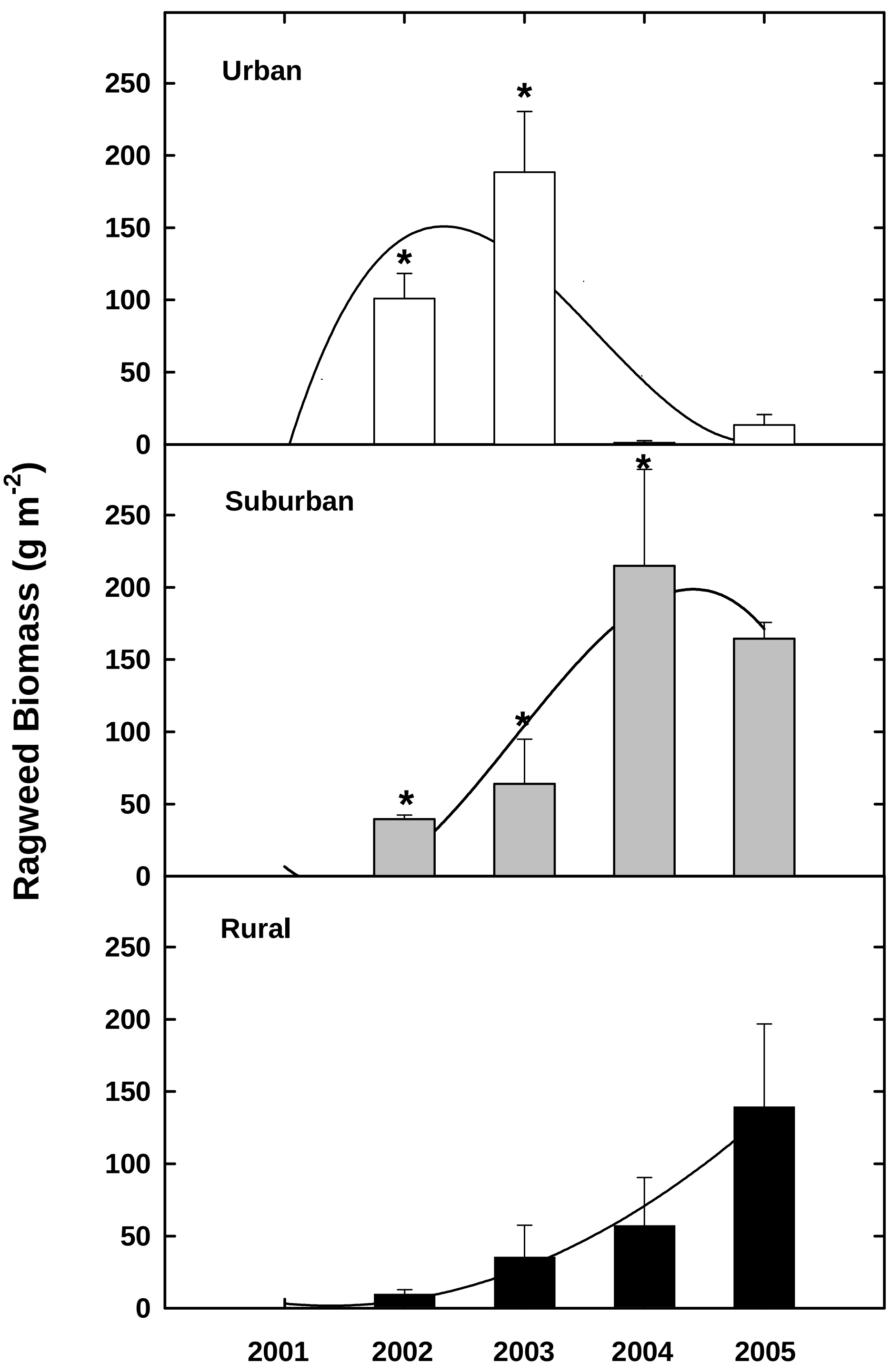
Urban
Suburban
Rural
Ragweed Biomass (g m-2)
0
50
100
150
200
250
2001
2002
2003
2004
2005
*

Figure 4

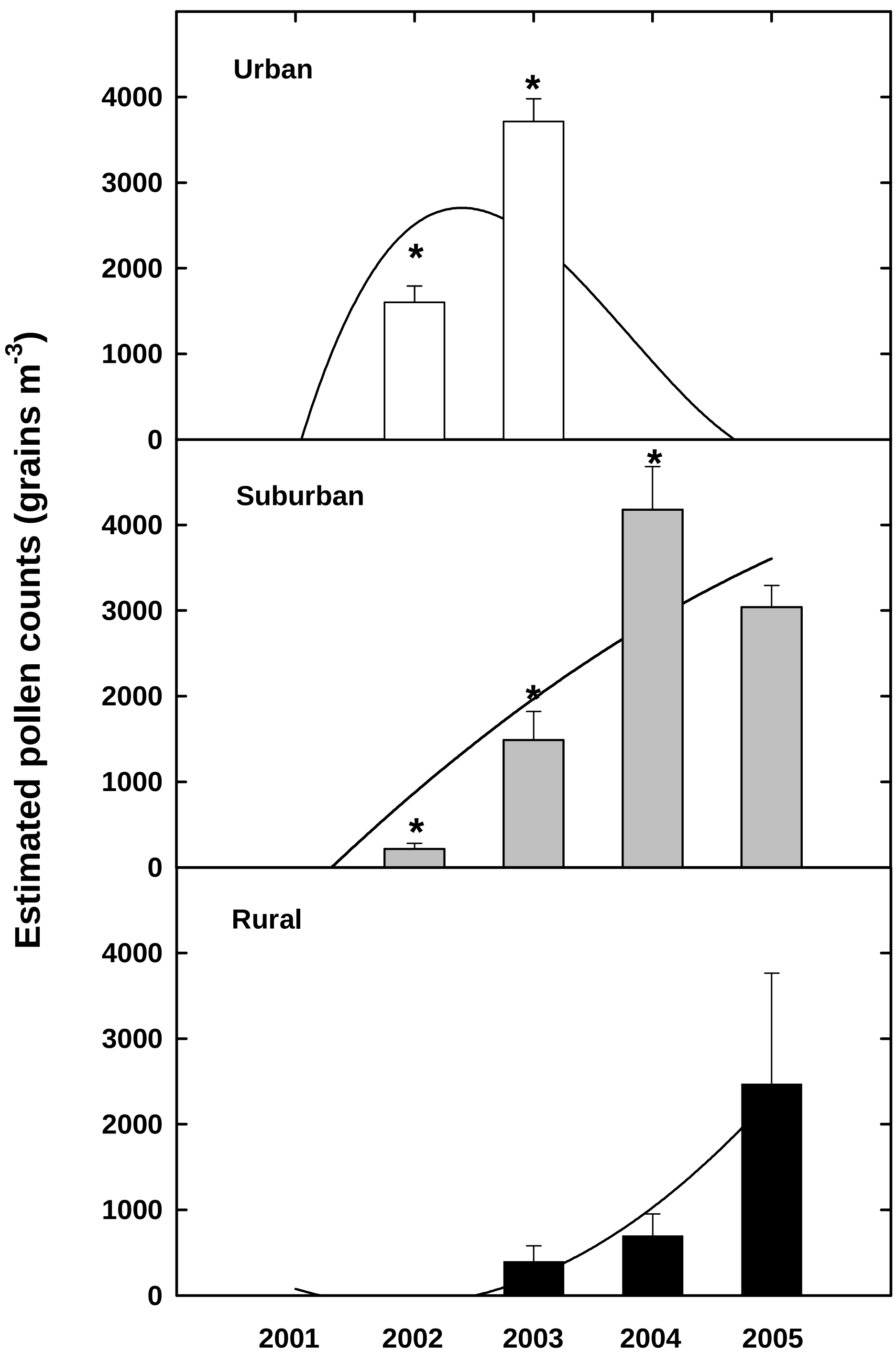
Estimated pollen counts (grains m-3)
Urban
Suburban
Rural
0
1000
2000
3000
4000
*
2001
2002
2003
2004
2005

Figure 5

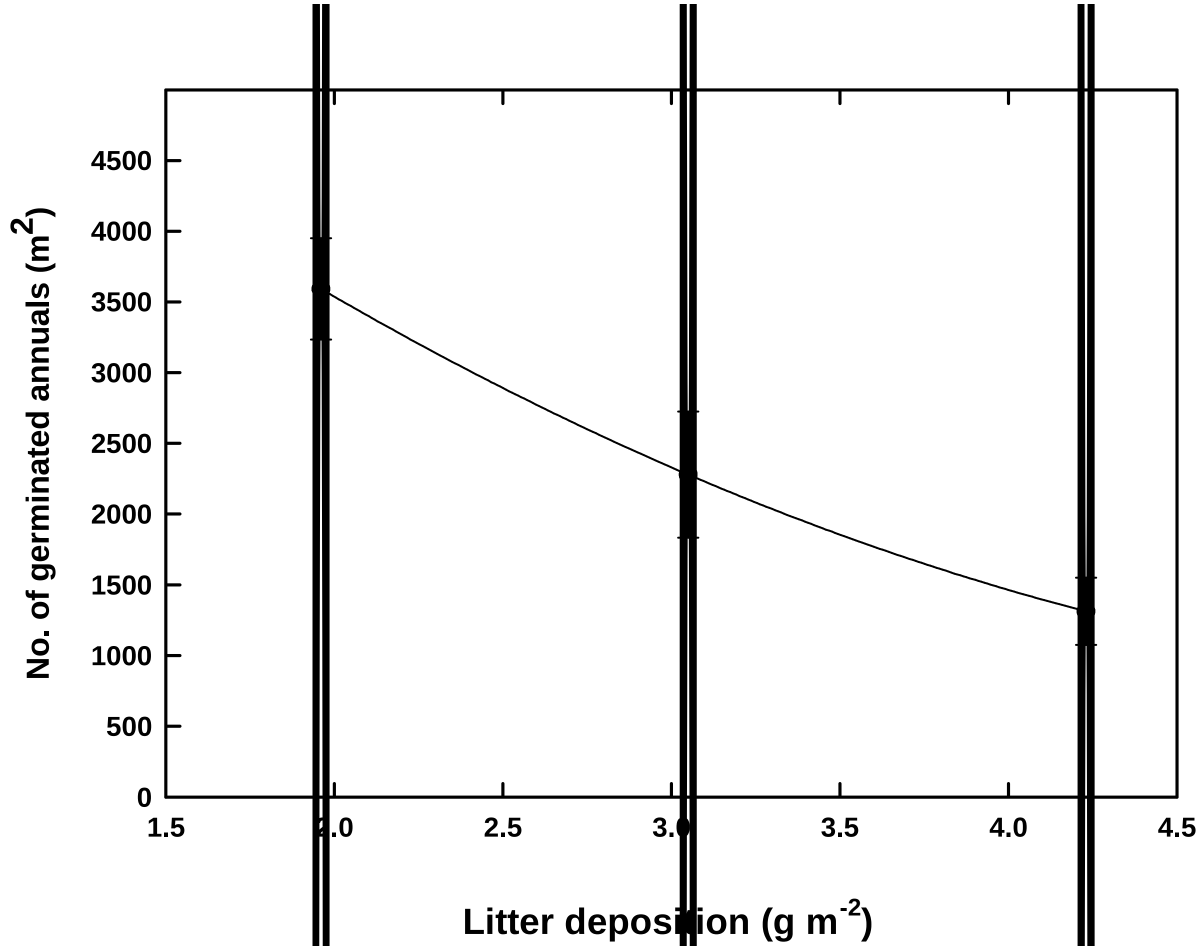
4500
4000
3500
3000
2500
2000
1500
1000
500
0
No. of germinated annuals (m2)
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Litter deposition (g m-2)

Figure 6