Quantifying Seed Production by Volunteer Canola (*Brassica napus*) and *Sinapis arvensis*[1]

*Quantificar a Produção de Sementes de Canola Voluntária (**Brassica napus**) e **Sinapis arvensis***

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ABSTRACT - Volunteer canola (*Brassica napus*) and *Sinapis arvensis* are well identified weeds of different cropping systems. Quantitative information on regarding seed production by them is limited. Such information is necessary to model dynamics of soil seed banks. The aim of this work was to quantify seed production as a function of the size of those weeds. A wide range of plant size was produced by using a fan seeding system performed at two sowing dates (environments). Plant size varied from 3 to 167 g per plant for canola and from 6 to 104 g per plant for *S. arvensis*. Seed production ranged from 543 to 14,773 seeds per plant for canola, and from 264 to 10,336 seeds per plant for *S. arvensis*. There was a close relationship between seed production per plant and plant size which was well-described by a power function ($y = 130.6x^{0.94}$; $R^2 = 0.93$ for canola and $y = 28x^{1.27}$; $R^2 = 0.95$ for *S. arvensis*). There was also strong relationships among the number of pods produced in individual plants and the quantity of seeds produced (g per plant) with the size of the plant. The relationships found in this study can be used in dynamic seed bank models of volunteer canola and *S. arvensis*.

Keywords: weed, plant size, density, planting.

*RESUMO - Voluntários de canola (**Brassica napus**) e **Sinapis arvensis** são conhecidas como plantas daninhas na produção agrícola. A informação quantitativa sobre a produção de sementes de ervas daninhas por estas é limitada. A informação é necessária para a dinâmica do modelo de bancos de sementes do solo. O objetivo deste trabalho foi quantificar a produção de sementes em função do tamanho destas plantas daninhas. Uma grande variedade de tamanho das plantas foi produzido usando-se um sistema de semeadura em leque, realizado em duas épocas de semeadura (ambientes). O tamanho da planta variou entre 3 e 167 g por planta para a canola e entre 6 e 104 g por planta para **S. arvensis**. A produção de sementes variou entre 543 e 14.773 sementes por planta de canola e entre 264 e 10.336 de sementes por planta para **S.arvensis**. Houve uma estreita relação entre a produção de sementes por planta e o tamanho da planta que foi bem descrita por uma função potência (y = 130,6x^{0,94}; R^2 = 0,93 para a canola e y = 28x^{1,27}; R^2 = 0,95 para **S. arvensis**). Houve também algumas fortes relações entre o número de vagens produzidas em plantas individuais e a quantidade de sementes produzidas (g por planta) com o tamanho da planta. Relações encontradas neste estudo podem ser usadas em modelos dinâmicos do banco de sementes de canola voluntária e **S. arvensis**.*

Palavras-chave: planta daninha, tamanho da planta, densidade, plantio.

INTRODUCTION

Canola (*Brassica napus*) cultivars with undesirable characteristic of dehiscent pods lead to shattering seeds easily after maturity and desiccation, and the shattered seeds enhance soil seed-bank of volunteer canola to a great extent. Volunteer canola is known as weed in the winter crop production fields such as winter wheat. Gulden et al. (2003) reported the average seed-bank additions of canola amounting to approximately 100 kg ha⁻¹

or 3,000 viable seeds m^{-2}, and is 20 times greater than the normal seeding rate of 4 to 5kg ha^{-1} for the crop. This leads to an extensive establishment of volunteer canola populations (Lawson & Friesen, 2006). Simard et al. (2002) reported that in Europe, canola seeds persisted in the soil for at least 5 years and volunteer plants were observed in the fields until 10 years after production (Knott, 1993; Lutman & López-Granados, 1998) whereas in western Canada, it was until 4years for volunteer plants (Thomas & Leeson, 1999). Reasons to increase volunteer canola in cropping system have been explained by using genetically engineered (GE) herbicide-resistant canola varieties and due to the rise in the annual seeded area of canola (Lawson & Friesen, 2006).

Sinapis arvensis is one of the persistent and emergent weed in winter crop production systems. It has been reported that *S. arvensis* populations of 20-80 plants m^{-2} resulted in a reduction of 19 to 77% in canola yield (Warwick et al., 2000). There are also some reports on yield reduction in other crops as for example flax, potato, and cabbage (Zeinali & Ehteshami, 2004). The weedy and troublesome nature of *S. arvensis* are explained by its strongly persistent seed-bank, competitive growth habit, and high fecundity (Warwick et al., 2000).

Soil seed-bank can be enriched through different mechanisms such as mechanical, wind, water, human-aided, animal aided, machinery and mimicry (Zimdahl, 2007), but established plants in crop fields are the main source of seeds in any soil seed-bank (Carvalho et al., 2005). Therefore, knowledge on seed production by weed species is necessary to understand the dynamics of soil seed-bank. Because weed and crop densities vary from field to field and affect seed production by the weed, a better substitute for density must be sought. Plant size is such a substitute, which reflects the effect of plant density and environmental conditions. Quantification of seed production as a function of plant size provides a simpler method for estimating weed seed production and an alternative to actually assessing seeds, which is very labor-intensive (Lutman, 2002). Several researchers have used this method to estimate seed production in weedy species (Thompson et al., 1991; Lutman, 2002; Grundy et al., 2004). However, quantitative information in volunteer canola and *S. arvensis* are scarce and come from limited range of plant sizes. Therefore, the aim of this work was to quantify the relationship between seed production and plant size in volunteer canola and *S. arvensis* over a wide range of plant size and seed production. This study is part of a comprehensive study to model seed-bank dynamics of volunteer canola and *S. arvensis*.

MATERIAL AND METHODS

Data collection

The experiments were carried out on Research Farm of Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran (36°51' N, 54°16' E and 13 m altitude; temperate sub-humid climate). Seeds used for planting were collected from canola fields around Gorgan during May 2009.

The experimental design to study the effect of plant density was a fan design (Figure 1). Each experimental plot was 8 x 8 m (64 m^2) and seeds were sown in 11 rows. One corner of each plot was chosen as the beginning of planting rows with inter-row spacing considered to zero and as the rows stretched away at the opposite sides, the inter-row spacing became to 1.5 m (Figure 1). To create more variation in plant size and seed production, the design was carried out at two
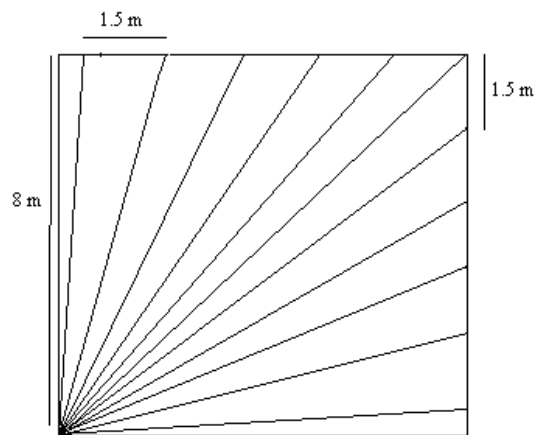

Figure 1 - Fan design plot used for planting. There were 4 plots for volunteer canola and *Sinapis arvensis* in two planting dates and each plot had 11 planting rows.

planting dates (November 16 and December 14, 2009) as to depict different environmental conditions. Seeds were planted with 2-5 cm intra-row spacing of and increased to 5-10 cm with two times hand thinning. At the harvest time, a 0.5 m wide margin was left around each plot and the remaining area of each plot (49 m²) was divided into 49,1 x 1 m (1 m⁻²) girds. Thus, there were 98,1 x 1 m sub-plots across the sowing dates for each species. To prevent seed shattering, sub-plots were harvested just before harvest maturity. At the harvest time, all mature plants were collected from each sub-plot and three randomly selected plants from each sub-plot were bagged separately.

In the laboratory, it was carried out measurements on plant height (cm), main stem node number, number of pods per plant, seeds per pod, seeds per plant, dry weight of pods (g per plant), seed dry weight (g per plant), 100-seeds dry weight (mg 100 seeds⁻¹) and plant size (g per plant). After measuring plant height and counting node number, pods were counted by hand. The pods were removed from the plants and the seeds were extracted, by hand, from the pods and were counted by hand. All the plant material was retained, oven-dried at 70 °C for 48h and weighed. Hundred-seed-weight was determined by counting and weighing 100 seeds manually.

Data analysis

The relationship between plant density and plant size (g per plant) was quantified by using a power equation:

$$y = ax^b \qquad \text{[eq. 1]}$$

in which, y = plant size, x = density and a and b = parameters. The same equation was used for modeling the relationship between the number of seeds produced per plant, number of pods per plant and seed production (g per plant) with plant size (g per plant). For the relationship between seed number per pod and 100-seed weight with plant size, a simple, linear regression model was used:

$$y = a + bx \qquad \text{[eq. 2]}$$

in which, y = number of seeds per pod or weight of 100 seeds, x = plant size (g per plant) and a and b = parameters.

Equations (1) and (2) were fitted to the data by PROC NLIN and PROC REG of SAS (Soltani, 2007). PROC MEANS was used to calculate variations and means for the studied variables (Soltani, 2007).

RESULTS AND DISCUSSION

Figure 2 presents changes in precipitation and temperature during the growing season from sowing to harvest time of canola and *Sinapis arvensis*. Both planting dates of *S. arvensis* matured 9 days after canola maturity in the second planting date. Early maturity of sowing date 2 of *S. arvensis* must be a result of higher temperatures during seed filling period (Figure 2). Growing season precipitation was 328 mm for the first sowing date and 255 mm for the second sowing date. Averagegrowing season temperature was 12.4 and 13.0 °C for canola at first and second sowing dates, respectively. Such values for *S. arvensis* were 12.7 and 13.5 °C.

The design and sowing dates resulted in a wide range of plant density. Plant density varied from 3 to 128 plants m⁻² for canola and from 5 to 162 plant m⁻² for *S. arvensis*. Other plant traits studied showed a similar variation. Plant size (g per plant) ranged widely from 3 to 167 g per plant for canola, and 6 to 104 g per plant for *S. arvensis*. Average plant size for canola and *S. arvensis* was 37.8 and 32.8 g per plant (Table 1). Average plant height of *S. arvensis* (177 cm) was higher than canola (111 cm) and varied from 90 to 144 cm for
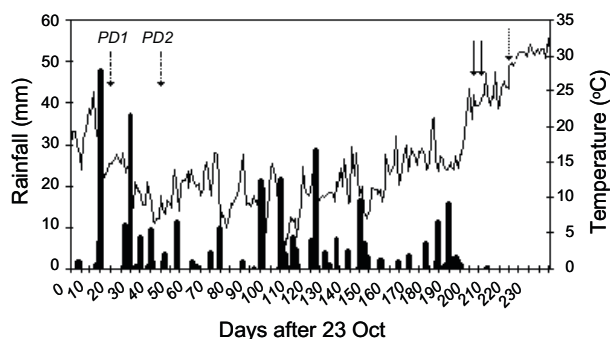

Figure 2 - Mean daily air temperature (black line) and mean daily rainfall in the growing season. PD1 and PD2 show planting dates on 16 Nov. and 14 Dec 2009. Solid arrows indicate harvest dates for volunteer canola and dotted arrow show harvest date for both planting date of *Sinapis arvensis*.

Table 1 - Mean, standard error (STD), maximum and minimum of volunteer canola and *Sinapis arvensis* plant height (cm), nodes number, number of pods per plant, number of seeds per pod, number of seeds per plant, pods dry weight (g per plant), seed production (g per plant), seed dry weight (mg 100 seeds^{-1}) and plant size (g per plant)

	Mean	STD	Max.	Min.
Volunteer Canola				
Plant size	37.84	3.209	166.5	3.2
Plant height	110.78	1.086	144.7	90.0
Nodes number	6.79	0.082	9.0	5.3
Number of pods per plant	171.78	14.685	621.3	23.00
Number of seeds per pod	23.75	0.263	28.0	17.2
Number of seeds per plant	4103.75	356.899	14772.6	542.9
Pods dry weight	11.04	0.979	49.9	1.1
Seed production	10.80	0.965	48.6	0.9
Seeds dry weight	303.74	3.008	385.0	255.3
Sinapis arvensis				
Plant size	32.89	2.734	103.7	5.5
Plant height	177.32	1.286	204.7	137.0
Nodes number	18.14	0.216	24.7	14.0
Number of pods per plant	429.25	38.995	1335.7	48.7
Number of seeds per pod	5.93	0.071	8.4	4.7
Number of seeds per plant	2641.83	264.042	10336.0	264.3
Pods dry weight	8.86	0.805	28.6	0.9
Seed production	3.77	0.399	15.7	0.4
Seeds dry weight	144.79	2.040	188.5	105.1

canola and 137 to 205 cm for *S. arvensis* (Table 1). Number of nodes in the main stem was 5 to 9 for canola and 14 to 25 for *S. arvensis* (Table 1), which had no significant differences as affected by planting date and densities for both species. Maximum pod number per each canola plant was 621, whereas it was as twice as greater for *S. arvensis* and minimum pods number for canola and *S. arvensis* were 23 and 49 (Table 1). Maximum number of seeds produced per plant for canola and *S. arvensis* were 14,773 and 10,336, and were recorded for lower densities and the first planting date (Table 1). Minimum number of seeds per plant for canola and *S. arvensis* was 543 and 264, respectively, and it was performed at the highest densities in the second planting date (Table 1). Pod dry weight and seed production (g per plant) for canola did not vary largely. But, *S. arvensis* pods dry weight (9 g per plant) was about twice as much as the seed production (4 g per plant) (Table 1). The mean of seeds dry weight ranged from 255 to 385 mg 100 seeds^{-1} for canola, and from 105 to 189 mg 100 seeds^{-1} for *S. arvensis* (Table 1). Thus, thedesired range of plant size (g per plant) and seed production were obtained.

Plant size was closely dependent on plant density and decreased with the increase in plant density. This relationship was well-described by the power equation when R^2 coefficients were 0.89 and 0.93 for canola and *S. arvensis*, respectively. The *a* and *b* parameters were 251.6 and -0.64 for canola and these parameters were 483.1 and -0.86 for *S. arvensis*. The *a* parameter shows plant size at the plant density of 1 plant m^{-2}. According to the model, when density increased from 3 to 130 plant m^{-2}, plant size decreased from 125 to 11 g per plant for canola. Plant size of *S. arvensis* decreased from 104 g per plant at 6 plant m^{-2} to 6 g per plant at 162 plant m^{-2} (Figure 3).

Density and planting dates can have a great effect on seed production of species (Sester et al., 2004; Nurse & DiTommaso, 2005). High plant density led to decrease in individual plant size and the amount of seeds produced by the plant (Pacala & Silander, 1990). High plant density could also have delayed seed set (Wulff, 1986; Watkinson et al., 1989). Weiner et al. (1997) pointed that high plant densities have little effect on average seed
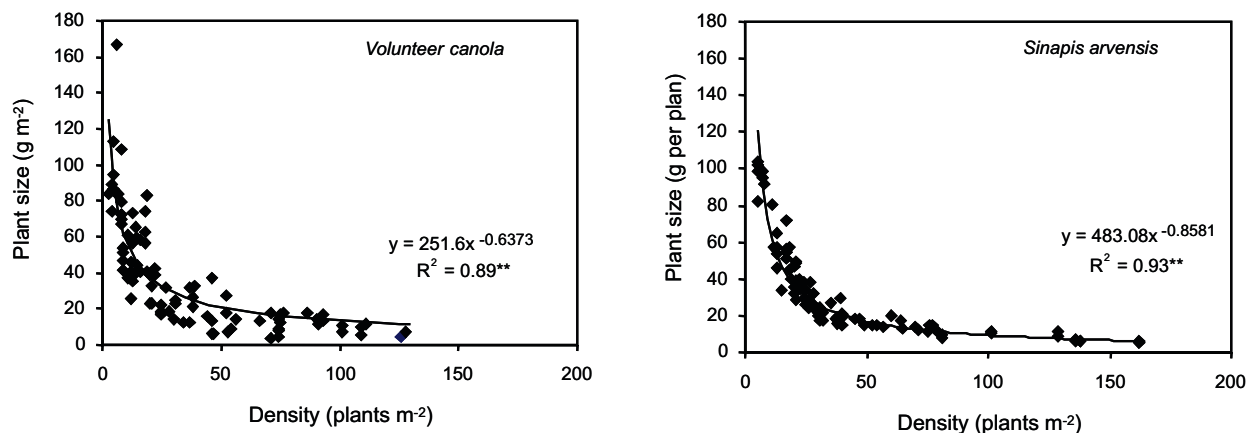
Figure 3 - Plant size (g per plant) as a function of plant density (plants m^{-2}) in volunteer canola and *Sinapis arvensis*.

weight. One of the most important causes of plant size and seed production in individual plants may be competition for nutrients and other resources (such as water and light), which limits individual plant growth. However, density and planting date effects will be no longer discussed in this work because these treatments were applied to obtain a wide range of plant sizes in order to quantificate seed production. Results indicated that these treatments were successful in creating a wide range of plant sizes (Table 1 and Figure 3).

Number of seeds per plant, number of pods per plant and weight of seeds per plant (g per plant) were described by using a simple allometric relation (y = αx^b) as a function of plant size (g per plant). R^2 values were 0.93 for seeds per plant, 0.92 for pods per plant and 0.98 for seed yield per plant. The *a* and *b* parameters estimate of power equation for volunteer canola are presented in Figure 4a, b, c, d and e.

According to these relationships, canola plants with a plant size of 1, 10 and 100 g per plant would produce approximately 130, 116 and 10,330 seeds per plant respectively and number of pods would be around 6, 50 and 417 per plant (Figure 4A and B). Plant size of 1, 10 and 100 g per plant lead to a production of 0.3, 3 and 29 g seeds per plant (Figure 4C).

A linear regression model showed that there was no relationship between seed number per pod and the weight of 100 seeds with plant size. Each pod would produce almost 24 seeds in canola (Figure 4D) and the weight

of 100 seeds was 305 mg (Fig 4E). Similar results were also obtained for *S. arvensis* (Figure 5). Relationships among number of produced seeds in individual plant, number of produced pods in individual plant and produced seeds (g per plant) and plant size (g per plant) could be properly describe by power equation inasmuch as R^2 coefficients were 0.95, 0.94 and 0.86, respectively (Figure 5A to C). The *a* and *b* parameters estimate of power equation for *S. arvensis* are presented in Figure 5A to E.

Plant sizes of 1, 10 and 100 g per plant would produce approximately 28, 526 and 9,884 seeds per plant, respectively and number of produced pods would be approximately 6, 94 and 1560 per plant (Figure 5A and B). Plant sizes of 1, 10 and 100 g per plant would produce 0.04, 0.8 and 16 g seeds per plant (Figure 5C). Number of seeds number per pod of *S. arvensis* increased linearly by increasing plant size (0.01 seed per g per plant), and the weight of 100 seeds increased 0.23 mg linearly by increasing plant size (Figure 5D and E).

Different methods had been used to estimate seed production in different species. Sester et al. (2004) evaluated weed beet growth and reproduction at a wide range of plant densities and in **various crops** (winter wheat, spring barley, spring pea, sugarbeet, maize and ryegrass). Those authors related bolting rate to flower and seed production per plant to density by using y = $1/(1 + a . density^b)$. Poggio et al. (2005) examined the effect of radiation and temperature during the seed set period on pod number per square meter (PN) and seed

number per square meter (SN) during grain filling on unit seed weight in field pea. They showed that both PN and SN were strongly correlated with the mean daily value of the photothermal quotient (PQ = incident radiation/ (mean temperature " base temperature)) for the seed-setting phase. Forcella et al. (2000) studied seed production of weedy species of *Setaria* in maize and soybean and indicated that viable seed
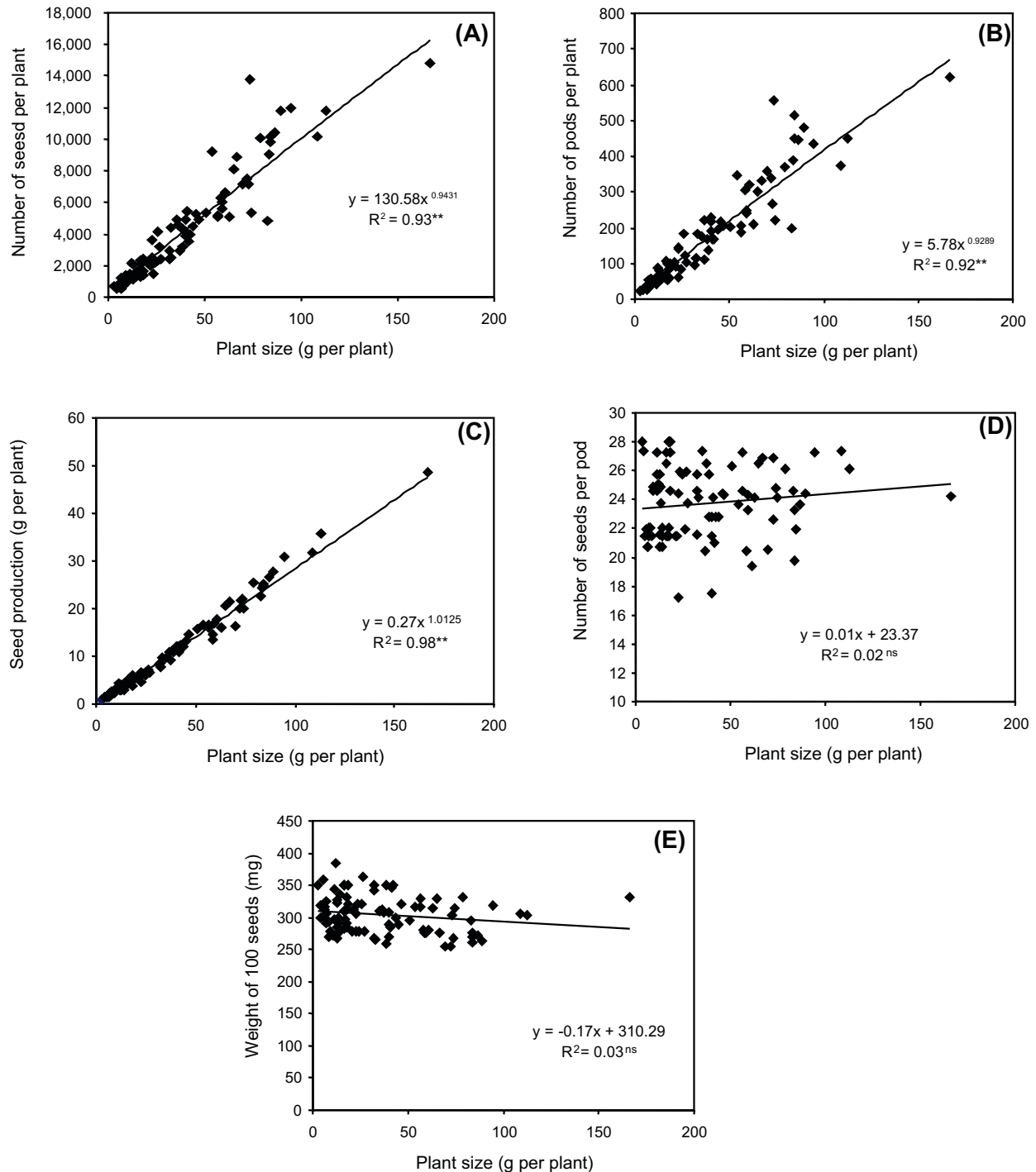

Figure 4 - Relationships between plant traits and plant size in volunteer canola. Plant traits are: number of seeds per plant (A), number of pods per plant (B), seed production (C), number of seeds per pod (D) and seeds dry weight (E).

production in *Setaria* was curvilinearly related to panicle length.

Some researchers have used a simple method to estimate seed production by weed

dry matter at harvest. Thompson et al. (1991) demonstrated a strong linear relationship between reproductive and vegetative weight. Cousens & Mortimer (1995) related fecundity to plant size by using a simple allometric
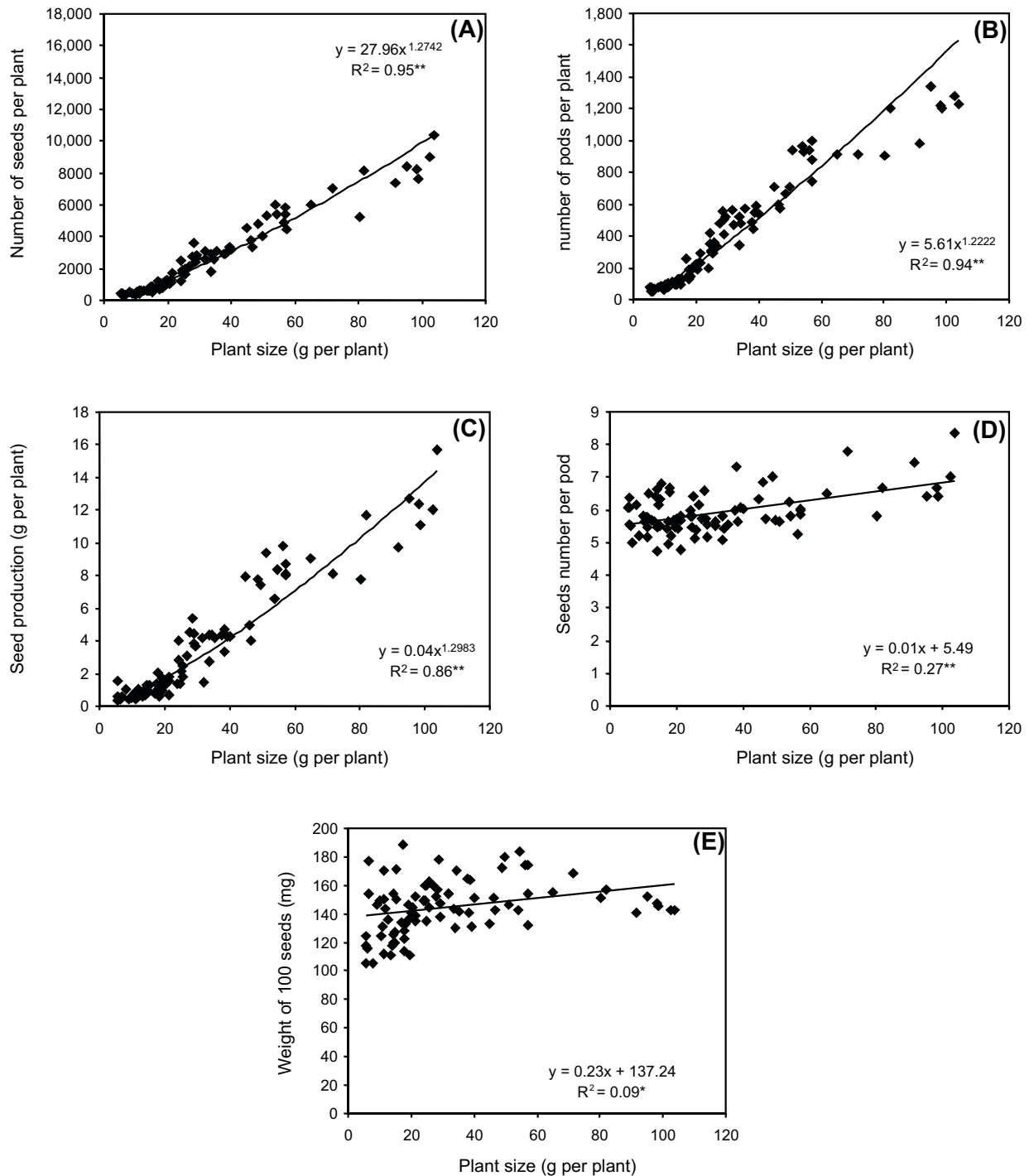

Figure 5 - Relationships between plant traits and plant size in *Sinapis arvensis*. Plant traits are: number of seeds per plant (A), number of pods per plant (B), seed production (C), number of seeds per pod (D) and seeds dry weight (E).

equation s = cW^k for many species, in which W = plant weight, s = seed number and c and k = parameters. Some recent works also statedhat seed production is related to plant size (Lutman, 2002; Grundy et al., 2004; Nurse & DiTommaso, 2005; Franke et al., 2007). Lutman (2002) used linear regression to quantify seed production of *Sinapis arvensis*, *Tripleurospermum inodorum* and *Stellaria media*. Grundy et al. (2004) showed that a linear relationship was adequate between logarithm of *Chenopodium album* seed production and logarithm of biomass which was robust over a range of competitive situations with onion and cabbageat different planting densities and in several growing seasons. Nurse & DiTommaso (2005) indicated that seed production of velvetleaf increased as biomass increased in a linear regression. Franke et al. (2007) observed that total seed weight had a strong linear correlation with the aboveground biomass of the mother plant and individual seed weight. It was little affected by the weight of the mother plant, however.

Overall, the results in this study indicated that there is an adequate relationship between seed production and plant size in both species. This relation is a key element in the construction of weed population dynamics models and the seed production of the volunteer canola and *S. arvensis* which can be used in the models (e.g. GENESYS by Colbach et al., (2001a, b) Sester et al., (2008) ALOMYSYS by Colbach et al. (2006). Weed population dynamic models can be used to explore the effect of management on weed numbers (Rasmussen et al., 2002). One key stage in the dynamics of weed population is the return of produced weed seeds back into the soil seed-bank. This study also will be helpful for future studies of volunteer canola and *S. arvensis* biology and ecology.

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