PLANT BREEDING AND SEED SCIENCE
Volume 70 2014

DOI: 10.1515/plass-2015-0015

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EFFECTS OF SEED VIGOR ON GROWTH AND GRAIN YIELD OF MAIZE

ABSTRACT

Reduction in seed vigor is a consequence of seed aging which may influence field performance of crops. Thus, a field study was conducted as RCB design with 6 replicates to evaluate the effects of seed vigor on maize (cv. Ksc 301) growth and yield. A sub-sample of maize seeds was kept as control and two other sub-samples were artificially aged for 9 and 12 days. So, three seed lots (V_1, V_2 and V_3), with different vigor were provided and sown in the field. Mean emergence time significantly increased, but mean emergence percentage decreased as seed vigor increased. The lowest leaf area index (LAI), dry matter accumulation (DMA) and crop growth rate (CGR) were obtained for plants from the lowest vigor seed lot (V_3). At the later stages of growth, the highest relative growth rate (RGR) was recorded for V_1 plants, followed by V_2 and V_3 plants. Poor stand establishment and growth of plants from V_2 and V_3 seed lots led to yield loss by 23.7 % and 41.5 %, respectively. These results showed that production and cultivation of high vigor seeds are necessary to ensure satisfactory field performance of maize.

Key words: emergence, germination, grain yield, growth, seed vigor

INTRODUCTION

Maize seeds are consumed by humans directly or after processing, and are often the main component of animal feed (Steduto *et al.*, 2012). The area devoted to this plant and the yield per hectare have been increasing over time, total production was 883 million tons in 2011 (FAO, 2013). Grains of a modern maize hybrid contain about 4% oil, 9% protein, 73% starch, and 14% other constituents (Laurie *et al.*, 2004). Field performance of maize may be influenced by many internal and environmental factors. One of the most important internal

Communicated by Grzegorz Żurek

factors which may affect field emergence and yield of maize is seed vigor (Ghassemi-Golezani *et al.*, 2011).

Seed vigor has been defined as, the sum of those properties that determine the activity and performance of seed lots of acceptable germination in a wide range of environments (ISTA, 2010). Ghassemi-Golezani (1992) reported that seed vigor may influence crop yield through both in-direct and direct effects. The indirect effects include those on percentage emergence which influence yield by altering plant population density and spatial arrangement. Direct effects are those on emergence rate which influence seed-ling vigor and uniformity. However, it is important to study seedling emergence and growth to understand seedling survival and recruitment. It was well established that high seed vigor can enhance seedling size via improving seed germination rate (Roberts and Osei-Bonsu, 1988; Powell, 2009; Ghassemi-Golezani *et al.*, 2011), but it is not clear whether this initial advantage can continue to have any impact on crop growth and development.

Plant growth analysis is considered to be a standard approach to study the growth and productivity of plants (Wilson, 1981). Study of growth pattern not only shows how plant accumulates dry matter, but also reveals the events which can make a plant more or less productive singly or in population (Ahad, 1986). Determination of the increase in dry matter is a suitable basis for photosynthetically active tissue and leaf area (Gupta and Gupta, 2005). The dynamics of dry matter distribution to various plant organs, their yielding and productivity may be characte-rized by using various indices of growth (Zajac *et al.*, 2005).

Three parameters commonly used in growth analysis are leaf area index (LAI) which is leaf area per unit land area, crop growth rate (CGR) defined as the increase in plant tissue per unit of time and relative growth rate (RGR) expressed as the increase in plant tissue per unit plant tissue present per unit of time (Ghosh *et al.*, 2013). Leaf area index (LAI) accounts for the ability of the crop to capture light energy and is critical to understand the function of many crop management practices (Inge *et al.*, 2004). Attainment of high LAI intercepts and converts radiation into dry matter efficiently, and partitioning of the dry matter to the grains is the major requirement of a high grain yield (Tesfaye *et al.*, 2006). Growth parameters like optimum leaf area index (LAI) and crop growth rate (CGR) at flowering have been identified as the major determinants of yield (Sun *et al.*, 1999).

Productivity of crop canopies is usually expressed by the term crop growth rate (CGR) (Ramachandran Nair, 1993). CGR can alternatively be analyzed as the product of light interception (as determined by leaf area index and extinction coefficient) and the efficiency of use of intercepted light in dry matter production or in canopy net photosynthesis (Webster and Wilson, 1980). Relative growth rate (RGR) is a complex phenomenon that is determined by differences in physiology, morphology and biomass partitioning (Shipley, 2006). In fact, the main reason for examining relative growth rates is to eliminate growth differences that arise from initial size differences (Wareing, 1966). Another reason to examine relative growth rates is to determine which seedlings are more efficient (Brand, 1991). However, combination of growth parameters explain different yields better than any individual growth variable (Ghosh and Singh, 1998). A larger leaf area, high dry matter production, superior crop growth rate and high relative growth rate at the vegetative stage result in great grain yield (Mondel *et al.*, 2011).

A better understanding of crop growth and partitioning of assimilates into economical yield for plants from different vigor seed lots would help to expedite yield improvement of field crops such as maize. Thus, this research was undertaken to investigate the pattern of growth and grain yield of plants from high and low vigor seeds of maize.

MATERIALS AND METHODS

Seeds of maize (*Zea mays* L. cv. Ksc301) were obtained from Seed and Plant Improvement Institute of Karaj, Iran. Seeds were stored at 5 ˚C until the investigation began. These seeds were divided into three sub-samples. A sub-sample was kept as control or high vigor seed lot (V_1) and two other sub-samples with about 16 % moisture content were incubated at 40 °C for 9 and 12 days (V_2 and V_3, respectively), using rapid aging test (Ellis and Roberts, 1980). As a result, the three seed lots with 98 %, 92 % and 88 % normal germination and different levels of vigor (V_1, V_2 and V_3) were provided.

The field experiment was conducted in 2010 at the Research Farm of the University of Tabriz, Iran (latitude 38°05′N, longitude 46°17′E, altitude 1360 m above sea level). The soil was sandy loam with EC of 0.68 ds m^{-1}, pH of 8.1 and field capacity of 28.8 %. The experiment was arranged as randomized complete block design with six replications. Seeds were treated with Benomyl at a rate of 2 g kg^{-1} before sowing and sown on prepared plots at a depth of about 4 cm in May 2010. Seeding rate was 10 seeds m^{-2}. Weeds were controlled by hand during crop growth and development. Number of seedlings emerged in each plot was counted in daily intervals until seedling establishment stabilized. Mean emergence percentage was then determined and mean emergence time (MET) was calculated according to Ellis and Roberts (1980):

$$MGT = \frac{\sum(D \times n)}{\sum n}$$

After seedling establishment, two plants from each plot were harvested with 15 days intervals, starting 35 days after sowing up to crop maturity. Leaf area of harvested plants was measured by a leaf area meter (model LI-3100). The following equation was used to calculate LAI:

$$LAI = \frac{L}{P}$$

where L is leaf area and P is ground area, respectively. Then plants from each plot were dried separately in an oven at 75 °C for 48 hours. The data were used to show changes in dry matter accumulation during plant growth and development. CGR and RGR were calculated as:

$$CGR = (b + 2ct) \times e^{a+bt+ct_2}$$

$$RGR = b + 2ct$$

where t is days after sowing, e is the base of the natural logarithms and a, b and c are constants.

At maturity, plants in 1 m^2 of each plot were harvested and grain yield per unit area was determined. Analysis of variance of the data was carried out using MSTAT-C software. Duncan test was applied to compare means of each trait at $p \leq 0.05$. Excel software was used to draw figures.

RESULTS

Analysis of variance showed that percentage and time of seedling emergence significantly affected by seed vigor ($p \leq 0.01$). Seedling emergence percentage for high vigor seed lot (V_1) was considerably higher than that for low vigor seed lots (V_2 and V_3). Mean seedling emergence percentage decreased, but emergence time significantly increased with decreasing seed vigor. Seedlings from V_1 seed lot emerged about 5 and 6 days earlier than those from V_2 and V_3 seed lots, respectively (Table 1).

Table 1

Comparison of means of seedling emergence percentage and time of maize affected by seed vigor

Seed vigor	Emergence [%]	Emergence time [days]
V1	82.08a	9.55b
V2	44.72b	14.26a
V3	37.36b	15.55a

V_1, V_2 and V_3: Seed lots with 98 %, 92 % and 88 % germination, respectively

Regression curves fitted on leaf area index (LAI) at different stages of growth and development (Fig. 1) showed that LAI for plants from all seed lots increased with time up to a point where maximum LAI was recorded. Maximum LAI of plants was observed at 80-90 days after sowing, depending on seed vigor. Thereafter, LAI for plants from all seed vigor lots decreased. The highest LAI at all stages was obtained for plants from the highest vigor seed lot (V_1), followed by those from V_2 and V_3 seed lots.

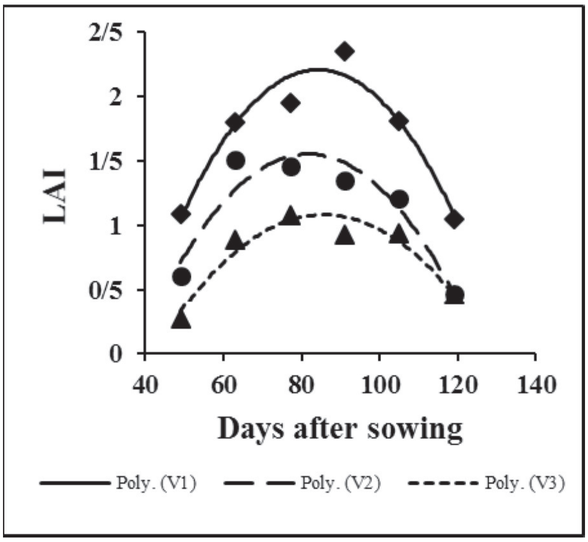

Fig. 1. Leaf area index (LAI) of plants from different vigor seed lots.
V_1, V_2 and V_3: seed lots with 98 %, 92% and 88% germination

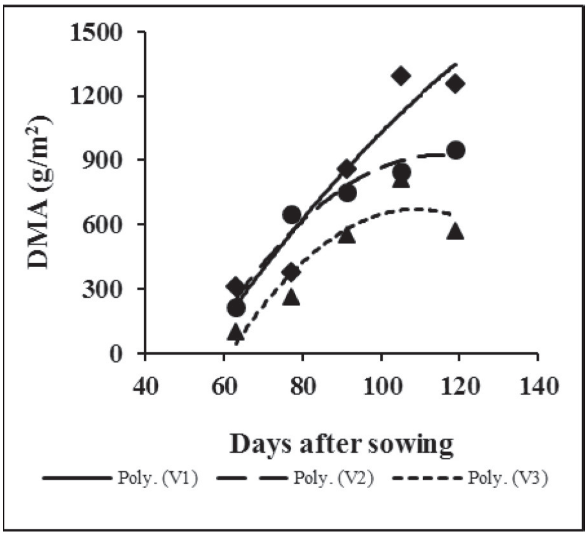

Fig. 2. Dry matter accumulation (DMA) of plants from different vigor seed lots.
V_1, V_2 and V_3: seed lots with 98%, 92% and 88% germination

Dry matter accumulation (DMA) of plants from high vigor seed lot (V_1) increased until last harvest. DMA of plants from low vigor seed lots (V_2

and V_3) enhanced up to a point where maximum DMA produced and then gradually decreased. Differences in DMA among plants from various seed lots were more pronounced at later stages of growth, where the highest DMA was achieved by plants from V_1, followed by V_2 and V_3 plants (Fig. 2).

Crop growth rate (CGR) of V_1 plants increased up to about 102 days after sowing and thereafter, stated to decrease. However, maximum CGRs of V_2 and V_3 plants were recorded at about 80 and 77 days after sowing, respectively. Maximum CGRs of V_1 and V_2 plants were almost similar, but maximum CGR of V_3 plants was much lower than plants from other seed lots (Fig. 3a).

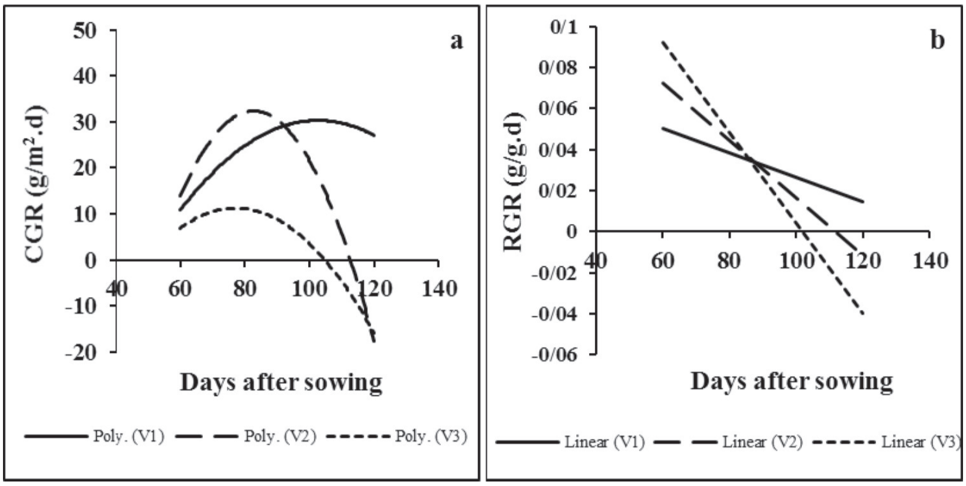

Fig. 3. Changes in CGR and RGR of maize plants from various seed lots.
V_1, V_2 and V_3: seed lots with 98 %, 92 % and 88 % germination

Relative growth rate (RGR) of plants from all seed lots linearly decreased with progressing plant growth and development. The rate of reduction in RGR was higher for plants from V_2 and V_3 seed lots, compared with plants from V_1 seed lot. RGR of V_3 plants at the earlier stages of growth was more than that of V_2 and V_1 plants. RGR of plants from all seed lots was similar at about 86 days after sowing, but at late stages of growth the highest RGR was recorded for V_1 plants, followed by V_2 and V_3 plants (Fig. 3b).

The effect of seed vigor on grain yield per unit area was also significant ($p \leq 0.05$). The highest grain yield per unit area was obtained for plants from high vigor seed lot (V_1), followed by those from V_2 and V_3 seed lots (Fig. 4).

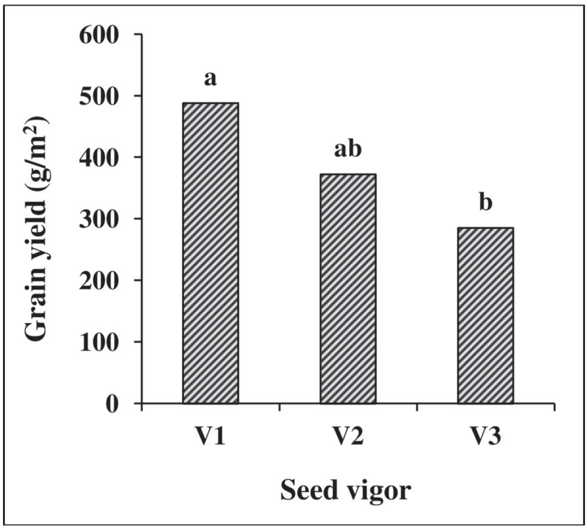

Fig. 4. Grain yield of plants from different vigor seed lots.
V_1, V_2 and V_3: seed lots with 98%, 92% and 88% germination

DISCUSSION

Reductions in seedling emergence due to seed aging and lowering vigor (Table 1) could be related to lipid peroxidation, mitochon-drial dysfunction and less ATP production (Mc Donald, 1999). Kapoor *et al.* (2010) showed that less seed vigor due to seed aging was the result of biochemical changes. Ellis (1992) reported that seed vigor influence on early growth of plant both directly through physiological injury or necrotic lesions and indirectly through percentage emergence and emergence rate. Similar results were reported for winter oil seed rape (Ghassemi-Golezani *et al.*, 2010).

Poor stand establishment of plants from low vigor seeds (Table 1) led to deductions in leaf area index (LAI) at different stages of growth and development (Fig. 1). Reductions in LAI of plants from different vigor seed lots at the later stages of plant development (Fig. 1) was due to senescence and shedding of some old leaves. New leaves were formed at the top, while bottom leaves received less light and eventually were shed. Soltani *et al.* (2009) also reported that leaf area of wheat plants reduced as a result of seed aging. Less leaf area means less photosynthesis which can potentially reduce final yield.

The lowest dry matter accumulation (DMA) for plants from the lowest vigor seed lot (V_3) at all stages of growth and development (Fig. 2) was the result of slow and poor establishment (Table 1). Similarly, Verma *et al.* (2003) found that reduction in seedling establishment due to seed aging can influence dry matter accumulation of *Brassica compestris*. Differences in dry matter accumulation of plants from high and low vigor seeds gradually enhanced at later stages of plant growth and development (Fig. 2), similar to that reported for seedling growth of wheat (Soltani *et al.* 2009).

The lowest crop growth rate (CGR) of plants from poor vigor seed lot (Fig. 3a) was the result of slow and scattered plant establishment. The least CGR of plants from the lowest vigor seed lot was associated with low LAI (Fig. 1) and DMA (Fig. 2) of these plants. Decreasing CGR of plants from all seed lots at the later stages of growth (Fig. 3a) was due to shedding of old leaves, particularly in V_2 and V_3 plants. According to Zajac *et al.* (2005) higher CGR is the result of greater LAI, light in-terception and dry matter production. Pederson and Lauer (2004) showed that seasonal crop growth rate patterns, total dry matter and leaf area index were highly associated with each other.

Linear reduction in RGR of plants from all seed lots (Fig. 3b) clearly shows that some of the photosynthates allocated to non-photosynthetic tissues with progressing growth and development. Shedding of some old leaves led to the negative RGR of plants from low vigor seed lots at later stages of growth. Atkin (1996) found a positive correlation between whole plant photosynthetic rate on a mass basis and RGR. Since plants are composed largely of material derived from photosynthesis, increased allocation to non-photosynthetic organs should in general reduce plant growth rate (Mooney, 1972).

Poor stand establishment and low LAI (Fig. 1), CGR (Fig. 3a) and RGR (Fig. 3b) of plants from low vigor seeds with acceptable germinations (V_2 and V_3) at later stages of growth and development led to grain yield reduction of these plants by 23.7 % and 41.5 %, respectively (Fig. 4). Therefore, infirmity of plants from low vigor seeds in growth was associated with less grain yield. Strong relationship of plant growth parameters with grain yield per unit area was also supported by Ghassemi-Golezani *et al.* (2009) in faba bean. Loss of grain yield due to low vigor seeds was also reported for soybean (Saha and Sultana, 2008), chickpea (Biabani *et al.*, 2011) and oilseed rape (Ghassemi-Golezani *et al.*, 2010). These results clearly suggest that production and proper storage of high vigor seeds are necessary for satisfactory crop production.

CONCLUSION

The lowest leaf area index (LAI), dry matter accumulation (DMA) and crop growth rate (CGR) were obtained for plants from the lowest vigor seed lot (V_3). Poor stand establishment and growth of plants from low vigor seed lots led to considerable yield loss. Therefore, production and cultivation of high vigor seeds are necessary to ensure satisfactory field performance of maize.

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