OnLine Journal of Biological Sciences

Original Research Paper

Management of Source-Sink Balance for Maintaining Seed Vigor and Storability of Maize

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Article history
Received: 28-09-2020
Revised: 23-11-2021
Accepted: 08-12-2020

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Abstract: Defoliation was the major factor which directly affected to maize seed yield and quality basis on source-sink relationship. Thus, the objectives were to study the effect of source-sink balance management on corn seed vigor and storability and to determine the effect of defoliation treatments on maize yield, yield components and produced seed germination traits. The experiment was arranged basis on Split-Plot in Randomized Complete Block Design with four replications. Main plot was the pattern of leave cutting with 5 levels: D_1 = control, (without defoliating), D_2 = complete defoliation, D_3 = defoliating only under the ear, D_4 = remain 2 top leaves, D_5 = remain ear leaf. Sup-plot was leaf cutting dates which were C_1 = 7 days after silking, C_2 = 10 days after silking, C_3 = 13 days after silking and C_4 = 16 days after silking. Complete defoliation severely reduced ear weight, row number per ear, seed number per ear and 100 - seed weight ($P<5\%$). Defoliation treatments had much more significantly affected on produced seed germination and seed vigor traits. Leaf defoliation intensity and leaf position affected total dry matter. Conclusion, the leaf defoliation only below ears was useful for source-sink balance management, because it promoted the seed qualities and vigor following to principle of parasitic sink elimination.

Keywords: Maize, Source, Sink, Vigor and Storability

Introduction

Source capacity was determined by photosynthetic activity which related to availability of carbohydrate reserves (Uhart and Andrade, 1991). During effective grain filling period, the interaction between source capacity and sink strength (i.e., the source/sink ratio) would result in variation of final grain weight (Borrás and Otegui, 2001). Middle leaves of the stem had greater important role than the other leaves because of greater surface for light absorbing in the photosynthesis. Completely defoliation was led to minimum seeds yield because of decrease in seed weight and filled grain percent (Gifford *et al*., 1984). Distance of leaves and ear which participant in photosynthetic efficiency were important in a slight defoliation. Top leaves of the ear transferred about 23 to 91 percent of photosynthates to the cob and the greatest number of transferred materials belonged to the nearest leaf on top of the ear (Collantes *et al*., 1997). Defoliation treatments imposed when the numbers of grains had been established to reduce the source/sink ratio then results in a sharp decreasing of soluble carbohydrates in stems (Uhart and Andrade, 1995).

According to (Borrás *et al*., 2004), the imbalance of source/sink ratio during post-flowering could dramatically reduce final kernel weight. Restricting the source capacity during the effective grain-filling period effected Kernel Water Content (KWC) and the differently dynamics of dry matter deposition. Shortage of assimilate availability per grain (post-flowering source/sink ratio) in case that promoted by low irradiance values or defoliation might be reflected on both kernel weight and kernel composition (Borrás *et al*., 2002). The analysis source/sink ratio during post-flowering stage which effect on kernel weight determination would improve the understanding of the magnitude and source limitations during grain filling of maize (Borrás *et al*., 2009). The short period of maize leaf defoliation up to 50% did not had an adverse effect on maize grain and yield components (van den Boogaard *et al*., 2001). Remove of leaves in the pollination phase decreased dry matter and grain yield of maize significantly (Borrás *et al*., 2004).

Seed development was the period between fertilization, maximum fresh weight accumulation and seed maturation; it began at the end of seed development and continues till harvested (Mehta *et al*., 1993). Optimum harvesting period at seed matured helps to obtain better seed quality and harvesting stage influenced the quality of seed which related to germination, vigor, viability and storability. Storability of seeds was a major genetically character and is influenced by pre-storage history of seed, seed maturation and environmental actors during pre/post-harvest stages (Shaheb *et al*., 2015). Early harvested seeds would be low seed quality caused by immature and poorly developed and poor storage compared to seed harvest at physiological maturity (Khatun *et al*., 2009). Storability of seeds was influenced by pre-storage history of the seeds, seed maturation and environmental factors during pre-harvest and post-harvest (Tuite and Foster, 1979).

Materials and Methods

The experiment was supported by Syngenta seed (Thailand) Co. Ltd.in research place and plant material, two experiments were conducted at the experimental field where located at U-Thong district, Suphan Buri province, Thailand. During the 2018 and 2019 growing seasons.

Plant Sampling Management and Experimental Design

In 2018, F_1 maize hybrids were planted 10 December the experiment was arranged into Split-plot in Randomized Complete Block Design with four replications.

Main-plot: The pattern of leave cutting with 5 levels were D_1 = control, (without defoliation), D_2 = complete defoliation, D_3 = defoliating leaves below the ear, D_4 = remain 2 top leaves, D_5 = remain ear leaf.

Sub-plot: Leaf cutting date with 4 levels were C_1 = 7 days after silking, C_2 = 10 days after silking, C_3 = 13 days after silking and C_4 = 16 days after silking.

In 2019, hybrids were planted 9 May in plots, again into Split-plot in Randomized Complete Block Design with four replications.

Plant materials and seed samples were F_1 hybrid maize seeds collected from parental hybrids lines for production. Plants were grown by 20x40 cm. of crop spacing. Compound fertilizer (15-15-15) at 60 kg h^{-1}, 40 kg h^{-1} after 3-5 days of germination, 20 kg h^{-1} after 40 days of emergence was applied for topping fertilizer single fertilizer (46-0-0) was applied as basal fertilizer amount 50 to 30 kg h^{-1} divided at 20 days after emergence and 15 kg after h^{-1} 40 days after emergence. Droplet irrigation was applied once a week. Weeds were controlled herbicides by spraying (2.4-D, glufosinate1.0 L h^{-1} + fluroxypyr 0.3 L h^{-1}).

Plants were harvested when at 110 day after emergence. After each harvest, samples containing 10 ears were placed in paper bags and then taken to a hot air oven for drying at 40°C. The drying was performed until the seeds reached approximately 12% of moisture content. Seeds were stored in plastic sealed bag in 25°C. Then, seeds were sampling for seed qualities and vigor was tested at 6th month.

For the sampling, five plants were used as represent from each sampling block then separated each plant part and dried. Data collection was consisting of seed yield (gram), row number per cob, seed number per row and ear weight and 100-seed weight with remarkably that seed samples were bulk in each sampling block before the measurement.

Seed Parameters

Seeds of maternal plants were stored for 6^{th} month then used for the seed parameters measurement, the effect of maternal environment was studied by testing seed germination traits. Seed qualities were tested following.

Determination of Germination Percentage

Germinations were carried out according to (ISTA, 2020). For each treatment, 100 seeds were germinated by using between paper techniques with four replications. The rolled papers were cultivated at room temperature (25±2°C). After the first count and final count 4 and 7 days after germination, normal, abnormal and diseased seeds were counted. Seed germination was calculated by the following formula:

$$Seed\ germination\ (\%) = \frac{No.\ of\ seeds\ germinated}{Total\ seeds} \times 100$$

Measurement of Root and Shoot Length

Final count, five seedlings were randomly selected as a represent for study, taking from each replicate of each treatment. The seedlings were cut into root and shoot parts and their lengths were measured as centimeter (cm).

Determination of Seed Vigor

Seedling vigor parameters were testing followed up protocols which were determined by ISTA: The Accelerated Aging test (AA) (ISTA, 2020), speed of germination (ISTA, 2020) and seedling growth rate (ISTA, 2020). These tests would predict storage and field planting potential. High humidity and high temperature stress were imposed on the seed, which was incubated for a period under these conditions, then transferred to a growth chamber to assess germination potential. Seed lots that withstand these conditions, while maintaining a germination rate of 90% or above, are considered high vigor (ISTA, 2020).

Speed of Germination

This parameter was calculated by the following formula given by ISTA, (2020):

$$Speed\ of\ germination = n1/d1 + n2/d2 + n3/d3$$

Where:
n = Number of germinated seeds
d = Number of days

Seedling Growth Rate Test

This test was closely related to the standard germination test and is useful to figure out field planting potential under optimal or near ideal conditions. Seeds were planted under optimal condition and promoted to grow for an extended period, usually several days past the typical germination period. The seedlings are evaluated by their growth characteristics, such as stem length, leaf development or root branching (ISTA, 2020).

The data were submitted to the Analysis Of Variance (ANOVA). Using a Split plot in Randomized Complete Block Design with 4 replications, mean comparisons were accomplished using a Least Significant Difference (LSD) test at the 5% level. Simple correlation analysis between the results obtained from each test method was conducted.

Results and Discussion

Ear Weight

Completely defoliation severely reduced ear weight in both years 2018 and 2019 (Table 1 and 4). Defoliating leaves under of the ear had greater ear weight than removing top leaves of the ear. Maybe it was due to that ear leaf acted as a parasitic sink for ear growth at grain filling period because it was in middle part of maize stem then easily shade on it. Reduction of leaf area reduced resources for grain filling (Koptur *et al*., 1996). According to leaf cutting date, leaves cut at defoliation in 13 days after silking (C_3) showed the highest ear weight (Table 4). A decreasing of source in the post-flowering source/sink ratio could reduce final kernel weight dramatically (Borrás *et al*., 2004). Ear weight was decreased significantly by early defoliation treatment (13 days after silking in both years had greater ear weight than 7 and 10 days after silking). Ear weight had shown to vary with environmental conditions that directly affect to plant growth and assimilate supply per kernel during the period when plants are setting their kernels (i.e., flowering) (Gambín *et al*., 2006). Differences in ear weight among hybrids and years were mostly affected by differences in the rate of kernel growth, as there were no differences in the duration of grain filling (Table 1 and 4).

Row Number Per Ear and Seed Number Per Row

Completely defoliation severely decreased row number per ear and seed number per row in both years 2018 and 2019 (Table 1 and 4). Reduction of supply assimilation by defoliations had significantly reduced row number per ear and seed number per row. Heidari (2012) reported, the row number per ear was harmful by complete defoliation. Minor effect of defoliation on seed number per row and row number per ear was due to that stem reserves can compensate insufficient photosynthesis from leaves. Defoliating top leaves of the ear produced lower seed number per row than defoliating leaves below ear. Upper leaves could be available to receive greater light than lower leaves, so defoliation of upper leaves had more adverse effect on seed number per row than lower leaves. Interaction between defoliation and leaf cutting date did significantly alter seed number per row concentration in 2018 year (Table 2). Interaction of D3 and C3 showed the highest row number per ear which was statistically significant (Table 5).

100-Seed Weight

The result of both years 2018 and 2019 showed, Removing all leaves severely reduced seed yield (Table 1 and 4). Defoliating leaves below the ear had greater amount of seed yield than defoliating leaves at the top of ear (D_4, D_5). It was probably due to that ear leaf in central part of maize stem and upper leaves can shade on it, so it becomes consumer and competes with ear for photosynthates. Lower seed yield of complete defoliation treatment was due to lower seed number per row and lower row number per ear. Defoliation treatments had significantly affected on 100-seed weight (Table 1 and 4) as same as the observed that defoliation decreased seed weight. It seems that seed weight is more dependent on genetic factors than environmental factors (Heidari, 2012).

Seed Germination Percentage

D_1 and D_3 had higher seed germination percentage than D_2, D_4 and D_5 in both years 2018 and 2019 (Table 3 and 6). It might be due to that defoliation as an environmental stress can reduce seed germination percentage as described by (Heidari, 2012). Defoliation of leaves top ear (D_4 and D_5) had no effected as great as a defoliation of leaves under ear (D_3). The reason was bottom leaves was currently senescent and available to receive low light so removal of them does have great effect on plant growth. According to leaf cutting date, leaves cut at defoliation in 13 days after silking (C_3) showed the highest seed germination percentage (Table 6).

DOI: 10.3844/ojbsci.2021.199.205

Table 1: Effect of defoliation patterns and leaf cutting date on total maize yield and yield components during 2018 (year 1)

Treatment[1/]	Ear weight, g/plant b	Row number per ear	Seed number per row	100 - Seed weight
Defoliation				
D_1	48.50a	12.58a	14.47a	26.84a
D_2	27.75b	9.96b	9.77b	10.99c
D_3	48.00a	12.21a	14.34a	28.84a
D_4	40.75a	12.03a	13.96a	23.27b
D_5	40.00a	11.53a	12.70a	23.05b
$LSD_{0.05}$	4.37	0.56	13.02	0.98
CV. (%)	9.51	1.22	28.36	19.60
Cutting date				
C_1	36.15b	11.15b	122.96a	23.20a
C_2	39.80ab	11.55ab	107.95a	23.21a
C_3	45.90a	11.65ab	122.83a	24.43a
C_4	42.15ab	12.28a	114.74a	23.54a
$LSD_{0.05}$	3.93	0.47	0.91	2.90
CV. (%)	7.92	0.96	22.32	6.19

a and b compared with LSD (P<0.05)
[1/] D_1 = control, (without leaf removal), D_2 = defoliating all leaves, D_3 = defoliating leaves under the ear, D_4 = remain 2 top leaves, D_5 = remain ear leaf
[1/] C_1 = 7 days after silking, C_2 = 10 days after silking, C_3 = 13 days after silking and C_4 = 16 days after silking

Table 2: The interaction of the defoliation patterns and leaves cutting date on seed number per row during 2018 (year 1)

	Seed number per row Cutting date			
Defoliation	C_1	C_2	C_3	C_4
D_1	14.98ab	15.43a	15.30a	12.16abcd
D_2	6.25e	8.38de	9.83cde	14.61ab
D_3	13.08abc	16.38a	14.00abc	13.56abc
D_4	13.56abc	15.53a	12.25abcd	4.65f
D_5	16.45a	13.35abc	10.50bcde	10.50bcde
LSD 0.05	2.04			
CV. (%)	4.12			

a, b, c, d, e and f compared with LSD (P<0.05)
[1/] D_1 = control, (without leaf removal), D_2 = defoliating all leaves, D_3 = defoliating leaves under the ear, D_4 = remain 2 top leaves, D_5 = remain ear leaf
[1/] C_1 = 7 days after silking, C_2 = 10 days after silking, C_3 = 13 days after silking and C_4 = 16 days after silking

Table 3: Effect of defoliation patterns and leaf cutting date on maize seed germination traits during 2018 (year 1)

Treatment[1/]	Germination, %	Shoot length, cm	Root length, cm	Seedling growth rate	Speed of germination	AA - test germination at 6th month
Defoliation						
D_1	90.78a	10.42ab	6.72b	2.15ab	22.50a	87.50ab
D_2	58.25c	6.79c	8.60a	1.98c	17.51c	59.75d
D_3	92.25a	11.22a	6.72b	2.21a	22.90a	90.14a
D_4	80.53b	7.91cd	7.99ab	2.06bc	20.78b	80.38bc
D_5	74.25b	8.75bc	7.69ab	2.14ab	20.91b	76.75c
$LSD_{0.05}$	5.56	0.88	0.69	0.06	0.63	5.86
CV. (%)	24.10	1.92	1.52	0.13	1.36	12.17
Cutting date						
C_1	81.00a	8.25a	7.69a	2.03a	20.89a	73.20a
C_2	86.00a	9.07a	7.93a	2.21a	20.63a	71.80a
C_3	64.00b	9.03a	7.25a	2.06a	21.63a	83.80a
C_4	78.20ab	9.72a	7.45a	2.14a	20.92a	66.40a
$LSD_{0.05}$	9.29	0.73	0.54	0.09	0.59	6.42
CV. (%)	19.80	1.48	1.10	0.19	1.19	10.15

a, b, c and d compared with LSD (P<0.05)
[1/] D_1 = control, (without leaf removal), D_2 = defoliating all leaves, D_3 = defoliating leaves under the ear, D_4 = remain 2 top leaves, D_5 = remain ear leaf
[1/] C_1 = 7 days after silking, C_2 = 10 days after silking, C_3 = 13 days after silking and C_4 = 16 days after silking

Table 4: Effect of defoliation patterns and leaf cutting date on maize yield and yield components during 2019 (year 2)

Treatment[1/]	Ear weight, g/plant b	Row number per ear	Seed number per row	100 - Seed weight
Defoliation				
D_1	62.01a	11.61ab	13.18ab	26.04a
D_2	29.80b	9.98d	9.99c	17.28d
D_3	61.71a	12.21a	13.80a	26.20a
D_4	30.80b	10.57cd	11.57bc	23.62b
D_5	38.75b	11.26bc	12.78ab	22.71c
$LSD_{0.05}$	7.15	0.38	0.79	0.40
CV. (%)	15.58	0.84	1.74	0.88
Cutting date				
C_1	38.11b	11.10a	12.54ab	22.85a
C_2	43.50ab	10.85a	12.28ab	23.18a
C_3	53.36a	11.66a	13.33a	23.19a
C_4	43.49ab	10.88a	10.91b	23.46a
$LSD_{0.05}$	4.98	0.50	1.08	0.49
CV. (%)	10.04	1.00	2.17	0.99

a and b compared with LSD (P<0.05)

[1/] D_1 = control, (without leaf removal), D_2 = defoliating all leaves, D_3 = defoliating leaves under the ear, D_4 = remain 2 top leaves, D_5 = remain ear leaf.

[1/] C_1 = 7 days after silking, C_2 = 10 days after silking, C_3 = 13 days after silking and C_4 = 16 days after silking

Table 5: The interaction of the defoliation patterns and leaves cutting date on row number per ear during 2019 (year 2)

	Row number per ear Cutting date			
Defoliation	C_1	C_2	C_3	C_4
D_1	12.06abc	11.05abcd	12.02abc	11.30abcd
D_2	10.33cd	10.03cde	9.24de	10.33cd
D_3	11.73abc	12.65ab	13.00a	11.45abc
D_4	10.78bcd	7.95e	12.46ab	11.09abcd
D_5	10.60bcd	12.558ab	11.60abc	10.25cd
LSD 0.05	1.12			
CV. (%)	2.26			

a,b,c,d and e compared with LSD (P<0.05)

[1/] D_1 = control, (without leaf removal), D_2 = defoliating all leaves, D_3= defoliating leaves under the ear, D_4 = remain 2 top leaves, D_5 = remain ear leaf

[1/] C_1 = 7 days after silking, C_2 = 10 days after silking, C_3 = 13 days after silking and C_4 = 16 days after silking

Table 6: Effect of defoliation patterns and leaf cutting date on maize seed germination traits during 2019 (year 2)

Treatment[1/]	Germination, %	Shoot length, cm	Root length, cm	Seedling growth rate	Speed of germination	AA - test germination at 6th month
Defoliation						
D_1	89.19a	9.65ab	6.75bc	1.47a	21.90a	83.19a
D_2	70.31c	6.22c	8.58a	1.23c	17.75c	64.31c
D_3	91.31a	10.41a	6.52c	1.50a	22.59a	85.31a
D_4	70.88c	7.23c	7.86abc	1.32bc	17.42c	64.88c
D_5	76.69b	7.94bc	7.98ab	1.41ab	18.90b	70.69b
$LSD_{0.05}$	1.19	0.94	0.65	0.05	0.50	1.16
CV. (%)	2.60	2.05	1.41	0.12	1.10	2.60
Cutting date						
C_1	78.35c	7.53b	7.70a	1.29b	19.24b	72.35c
C_2	79.45bc	8.44ab	7.78a	1.51a	19.61b	73.45bc
C_3	80.95a	8.09ab	7.36a	1.33ab	20.36a	74.95a
C_4	79.95ab	9.10a	7.30a	1.42ab	19.65b	73.95ab
$LSD_{0.05}$	0.72	0.78	0.53	0.09	0.32	0.51
CV. (%)	1.45	1.54	1.08	0.19	0.65	1.05

a, b, c and d compared with LSD (P<0.05)

[1/] D_1 = control, (without leaf removal), D_2 = defoliating all leaves, D_3 = defoliating leaves under the ear, D_4 = remain 2 top leaves, D_5 = remain ear leaf

[1/]C_1 = 7 days after silking, C_2 = 10 days after silking, C_3 = 13 days after silking and C_4 = 16 days after silking

Shoot Length and Root Length

Defoliation treatments had significantly impact on seedling shoot length and root length in both years 2018 and 2019 (Table 3 and 6). There had a negative correlation between root length reduced while shoot length, seedling growth rate and germination percent increased (Heidari, 2012).

Seed Vigor

The significantly effect of defoliation treatments on seedling weight and vigor was shown in both years 2018 and 2019 (Table 3 and 6). D_3 the best increased high seedling growth rate, speed of germination and AA test germination percentage after 6^{th} month of storage it's not significantly different from D_1. While the D_2, D_4 and D_5 still show low seedling growth rate, speed of germination and AA test germination percentage after at 6^{th} month of storage when compared with control which was no leaf removal (Table 3 and 6).

Defoliation leaves under ear severely (D_3) increased 100 - seeds weight, seed germination percentage, speed of germination and seed vigor. This might be due to those defoliating leaves under ear acting as a parasitic or metabolic sink that competed for ear and kernel development during the grain filling period. Those leaves at below part of the maize stem and upper leaves could provided shade for the leaves in the central position (Heidari, 2012). A senescent leaf undoubtedly reduces the supply of photosynthate available for distribution to the grain developing as indicated by the decline in stem weight and carbohydrate concentration (Jones and Simmons, 1983). If the defoliation leaves under ear severely, the quantity of retransferred assimilation from stem to grain would be increased. Defoliating leaves below the ear did not significantly decrease corn yield and seed quality (Koptur, *et al*., 1996).

Complete defoliation (D_2) caused the decreasing in yield and yield components. As same as study on grain maize showed, complete defoliation caused to diminish of the yield about 95% (Melchiori and Caviglia, 2008). Defoliation leaves on top of the ear (D_4 and D_5) caused more impact which decreased in the rate of grain filling because of only remained leaves were unavailable to supply enough to requirement of assimilate for plant. The effective period of grain filling had greater effected increasingly by defoliation than the rate of grain filling. The results suggest that the top leaves should be prevent for defoliate, because this treatment showed the negative effect on yield (Heidari, 2012). As reported by (Borrás *et al*., 2004), a decreasing of the post-flowering source/sink ratio could reduce final kernel weight dramatically. Matthews, (1973) reported large seed size could promoted the higher germination percentage (48%) while small seed size gave a lower germination percentage (46.0%) as same as the observing that germination was higher (89.6%) in large sized seeds and lower (85.2%) in small sized seeds. Storability of seeds was a major genetic characteristic and was influenced by pre-storage history of seeds, seed maturation and environmental factors during both of pre-harvest and post-harvest (Tuite and Foster, 1979).

Conclusion and Suggestions

The results of this study showed defoliating leaves under ear (D_3) could maintain seed storability with high seed germination percentage and seed vigor. The result in maize seeds had the potential to grow to normal seedlings in the field condition, compared to removing the top of the ear (D_4 and D_5). Therefore, improving the seed quality in maize, hybrids and agronomic practices should focus to promote the post-flowering source/sink ratio. The recommendation is to study the effect of other environmental factors such as light by removing leaves under and at the top of ear on seed qualities and storability is remarkably interesting. Finally, leaf defoliation at upper of ear was more impact to all investigated characteristics as well as the results that suggested the upper leaves should not defoliate, because this treatment has negative effect on the yield.

Acknowledgment

This work was supported by Syngenta Seeds (Thailand) Co. Ltd. for the source of maize seeds. We are grateful to farmer field at U-Thong district, Suphan Buri province for place of planting. Thank you Department of Agronomy, Faculty of Agriculture, Kasetsart University for working place at Crop Physiology and Renewable Energy Crops Laboratory, Seed laboratory and Prof. Dr. Michael Bredemeier at Georg - August University of Gottingen, Germany for supporting.

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