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Effect of Plant Density and Hand Weeding on Weed Control and Yield of the Vegetable Corn

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Abstract

Weed infestation has an adverse impact on the yield of vegetable corn. This study, therefore, aimed to investigate the effects of plant density and hand weeding on controlling weeds and yield of vegetable corn. The experiments were conducted in the field condition in a randomized complete block design with three replications. The planting densities were 79,365 plants ha^{-1} (D1); 92,593 plants ha^{-1} (D2); 111,111 plants ha^{-1} (D3); and 138,889 plants ha^{-1} (D4). The hand weeding treatments were no weeding (NW), hand weeding once at 3-4 leaf stage of vegetable corn (HW1), and hand weeding twice at 3-4 leaf and 8-9 leaf stages of vegetable corn (HW2). The results showed that the highest planting density combined with hand weeding was generally effective in controlling weeds. Furthermore, the increase in planting density combined with hand weeding significantly improved the physiological traits, which consequently increased the cob yield. The yield was optimum at D3 combined with hand weeding once. Thus, the results suggested that the optimum yield of vegetable corn could be obtained at a planting density of 111,111 plants ha^{-1} combined with hand weeding once at 3-4 leaf stage, an increase of the cob yield by 2.01 tons ha^{-1}.

Keywords

Planting density, hand weeding, vegetable corn, yield, weeds

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Introduction

Corn (*Zea may* L.), which is planted in 1.03 million ha producing around 4.87 million tons in 2018, is the second most important food crop in Vietnam after rice, (FAO, 2020). Corn is a multipurpose crop (e.g., used as human food, animal and poultry feed, and in industrial products) (Bibi *et al*., 2010). Corn can be planted and harvested young to take advantage of its fresh, sweet, and tender ears for vegetable purposes, called vegetable corn. Vegetable corn is a very young cob with undeveloped seeds (Nguyen *et al*., 2009), which has flavour and is rich in folate, providing 13% potassium, 14% B6 riboflavin, 17% vitamin C, and 11% fibber every four ounces (Fakir

& Islam, 2008). With the increasing interest in healthy foods worldwide, vegetable corn is a promising food due to its quality and safety.

There are several production constraints of corn, *i.e.* unavailability of seeds of improved and high-yielding varieties, high cost of agricultural practices and inputs, and susceptibility to various pathogens and insects, etc. Weed infestation is also considered an important constraint to corn production as weeds generally compete with the crop for light, nutrients, water, space, and allelopathy which reduce the yield and market value of the crop (El-sobky & El-naggar, 2016; Khanh *et al.,* 2018). Worldwide, yield losses in maize due to weeds are estimated to be approximately 37% (Kumawat *et al*., 2019) and reach as high as 90% (Dalley *et al*., 2006). Although various weed control measures (e.g., hand weeding, mechanical weeding, and the use of herbicides) are effective against weed infestation in corn, each control measure has its limitations. For instance, herbicidal control needs repeated applications due to the re-emergence of the weeds from the soil seed bank which may cause herbicide resistance in the long run with the same mode of action herbicides. Furthermore, excessive use of herbicides allows for the accumulation of toxicity in agricultural products, which has negative impacts on human health, soil, and water systems, and causes damages to biodiversity (Al-Samarai *et al*., 2018). Thus, there is a great demand for environmentally friendly approaches to weed management as alternatives to chemical weed control to maximize sustainability in agricultural production.

In this regard, hand weeding is still an effective conventional weed control method, if done properly. Dutta *et al*. (2016) showed that hand weeding significantly reduced weed dry weight and increased weed-control efficiency (88.3%), leading to increased nutrient uptake, thereby increasing the yield of vegetable corn by 69.9% over the weedy check. Kotru (2012) also showed that hand weeding was as effective as herbicide application, which increased vegetable corn yield attributes and total yield (by 33% and 29.2%, respectively) and reduced weed biomass and N-removal by weeds, relative to the weedy check. Furthermore, Kumar *et al.* (2017) also showed that hand weeding resulted in the lowest weed density and dry weight of all major weed species, followed by other herbicide applications, resulting in a significant increase in *rabi* maize yield. Overall, these studies generally showed that hand weeding is an effective nonchemical approach in weed management.

The frequency of hand weeding also greatly influences maize growth and yield but may not be economically feasible if yield largely depends on the timing of weed, especially at the critical stages of crop development (Abouziena *et al*., 2007). Vu & Ha (2015) reported that hand weedings at 3-4 leaf and 8-9 leaf stages of maize significantly lower weed density and weed biomass than single hand weeding at 3-4 leaf stage. Abouziena *et al.* (2007) indicated that there were no significant differences between hand weeding twice (at 3 and 6 weeks after sowing) or thrice (at 2, 4, and 6 weeks after sowing) in controlling weeds as well as yield. In addition, manual weeding is not always feasible due to the lack of labour in the proper time, higher labor cost, and unworkable condition of the labor (Kumar *et al*., 2017). Therefore, it is necessary to integrate different weed control techniques to achieve effective and sustainable weed control in vegetable corn production.

Planting corn at higher densities may increase its competitive ability upon the weeds. Higher planting densities have been used to suppress weeds and to increase the yield of the crop (Shapiro & Wortmann, 2006). In addition, optimum planting density plays an important role in efficient utilization of resources and the competitive balance between weeds and maize plants (El-Sobky & El-Naggar, 2016). Marín & Weiner (2014) and Youngerman *et al* (2018) found a strong negative relationship between corn density and weed biomass at different experimental sites when weed biomass would decrease as corn density increased. An increase in crop density could lead to the enhancement of the collective shade of weeds by the crops which suppressed weeds growth and prevented them from reaching the crop's initial size advantage (Marín & Weiner, 2014). Nguyen *et al*. (2009) recorded the statistically higher marketable yield of baby corn at the highest plant population (167,000 plants ha^{-1}). Moreover, Ghosh *et al.* (2017) revealed that baby corn yield reached the highest value at the density of 100,000 plants ha^{-1} and slightly decreased at the density of 120,000 plants ha^{-1}. According to Eskandarnejad *et al.* (2013), with increasing the plant population from a specific level, competition for light and nutrients became intense and the growth of plants was declined and crop yield would be reduced as a result.

Considering the above mentioned facts and views, the experiment was conducted to study the effect of hand weeding and planting density on the suppression of weeds and the yield of vegetable corn.

Materials and Methods

The experiment was conducted in spring cropping season in 2020 at the experimental fields of the Faculty of Agronomy, Vietnam National University of Agriculture. The seed of vegetable corn used in the experiment was LVN23, a good domestic variety and found more popular in the Vietnamese market (Nguyen, 2016). The seeds were produced by the Vietnam National Maize Research Institute.

The experiment was laid out in a Randomized Complete Block Design (RCBD) comprising 12 treatments with three replications. The planting density included four levels: 79,365 plants ha^{-1} with 60cm x 21cm (D1); 92,593 plants ha^{-1} with 60cm x 18cm (D2); 111,111 plants ha^{-1} with 60cm x 15cm (D3); and 138,889 plants ha^{-1} with 60cm x 12cm (D4). The hand weeding treatments were: no weeding (NW), hand weeding once at 3-4 leaf stage of vegetable corn (HW1), and hand weeding twice at 3-4 leaf and 8-9 leaf stages of vegetable corn (HW2). The selected planting densities were based on the previous study of Nguyen (2016), while the hand weeding was based on the previous study of Vu & Ha (2015).

One seed was sown and raised in a black plastic bag, after seven-day-old seedlings were transplanted into the field. Hand weeding was done by the use of a hand hoe. The fertilizer doses of 120 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1}, and 100 kg K_2O ha^{-1} were applied. All of the P_2O_5 was applied as basal during transplanting, while the N and K_2O were split equally into three applications during transplanting, at 3-4 leaf, and at 8-9 leaf stages of vegetable corn.

Weed species found during the experiment were identified at harvest from the non-weeding plot. Weed density (WD) was randomly determined within three quadrants ($0.25m^2$) placed from each plot at three growth stages, including 3-4 leaf stage, 8-9 leaf stage, and harvest stage. The weeds within each quadrant were oven-dried at 80°C for 48h and weighed to determine dry mass at the harvest. Weed control efficiency (WCE) was calculated based on the weed dry matter recorded in each treatment at the harvest stage of the crop using the formula suggested by Mani *et al.* (1973) as follows:

*WCE (%) = [(Weed dry weight in the unweeded (control) plot – Weed dry weight in the treatment plot)/Weed dry weight in the unweeded (control) plot] * 100.*

The physiological traits such as leaf area index (LAI) as well as dry mass of the crop were measured at the 7-9 leaf stage, tasseling stage, and last harvest stage using five-plant samples. The shoots were cut from the base and oven-dried at 80°C for 48h. The tassels and cobs were separated and weighed separately from the rest of the shoots.

Leaf area index (LAI) was calculated as the leaf area divided by the ground area, where leaf area was calculated by the length x the maximum width x 0.75 x the total number of leaves (Nguyen Van Loc & Nguyen Van Minh, 2019). At the harvest stage, the yield components such as the number of cobs were counted by averaging the number of harvested cobs from 10 randomly chosen plants of each experiment plot. Cob weight and cob yield were measured by weighing and adding up the total weight of young cobs that had green husk (Nguyen *et al.*, 2009).

Statistical analysis

The data were subjected to ANOVA for the planting density, hand weeding, interaction of planting density and hand weeding, and replication using IRRISTAT 5.0. The treatment mean differences were analyzed using least significant difference (LSD) at the 5% significance level.

Results and Discussion

Weed species

Weed species found in the experimental fields during the cropping period are presented for each weed group (i.e., grass, sedge, and broadleaf) (Suk *et al.*, 2005). The weeds were *Eleusine india*, *Cynodon dactylon*, *Echinochloa colona, and Leptochloa chinensis* under grasses, *Cyperus rotundus* under sedges, and *Eclipta alba*, *Rorippa indica, Portulaca oleracea, Physalis angulata,* and *Alternanthera* under broadleaf (**Table 1**). Spring season was characterized by incessant rain which resulted in higher weed density, especially *Cynodon dactylon, Eleusine india,* and *Leptochloa chinensis* (data not shown). Vu & Ha (2015) also reported that *Cynodon dactylon, Eleusine india,* and *Leptochloa chinensis* were the prevalent weeds in the maize field.

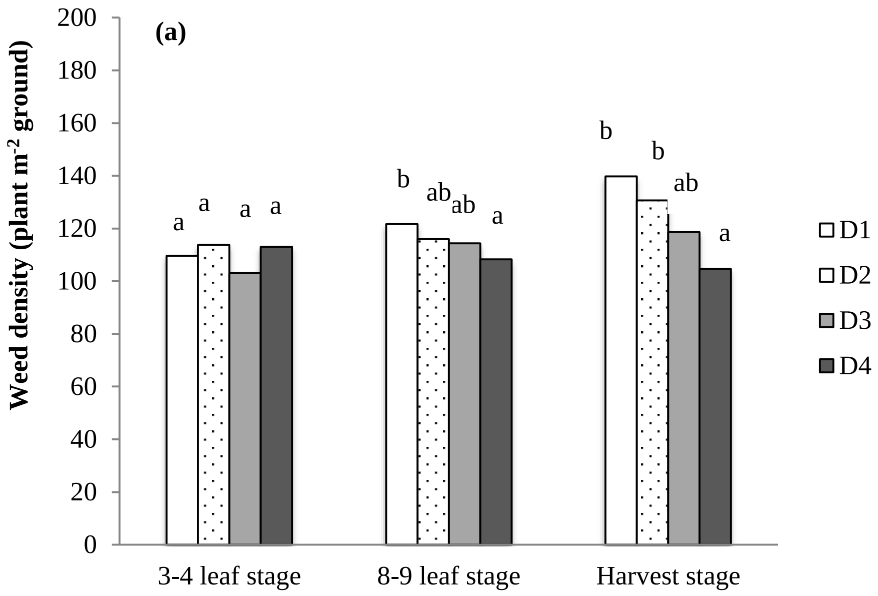
Weed density

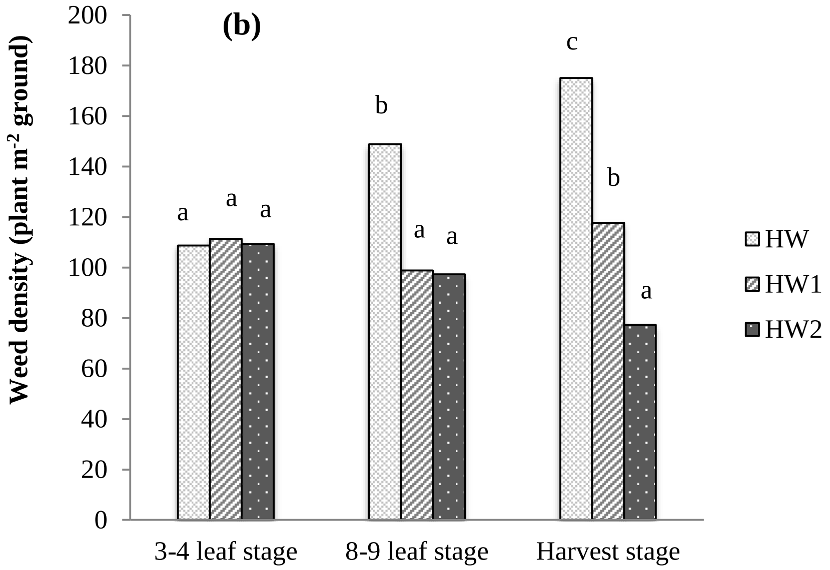
The effects of plant density and hand weeding on the weed density at 3-4 leaf stage, 8-9 leaf stage, and harvest stage of vegetable corn are presented in **Figure 1**. The results showed that the response of weed density to the plant density as well as the hand weeding was not significantly different ($P \leq 0.05$) at the 3-4 leaf stage. However, at the 8-9 leaf stage and harvest stage of vegetable corn, the weed density was significantly influenced *(*$P \leq 0.05$*)* by plant density (**Figure 1a**). The weed density decreased significantly with increasing plant densities from D1 to D4. This can be explained as an initial size advantage of crops in competition with annual weeds which is favored by the increased degree of size asymmetric competition caused by an increase in the crop density (Weiner *et al*., 2001).

In addition, there was a significant difference in weed density between no weeding and hand weeding at the 8-9 leaf stage and the last harvest stage of vegetable corn. In comparison with non-weeding treatment, hand weeding treatments significantly decreased weed density (**Figure 1b**). Khan *et al*. (2012) reported that hand weeding was the most effective way to control the weed density in the maize field. Furthermore, our results showed that hand weeding twice at 3-4 leaf and 8-9 leaf stages of vegetable corn significantly decreased the weed density in comparison with hand weeding once at 3-4 leaf stage of vegetable corn. These results confirmed the finding of a previous study that hand weeding twice significantly decreased weed density as compared with hand weeding once (Vu & Ha, 2015).

Table 1. Weed species in the experimental fields

No.	Botanical name	Family	Habit
A.	Grass		
1	*Eleusine india* (L.) Gaertn	Poaceae	Annuals
2	*Cynodon dactylon* (L.) Pers.	Poaceae	Perennials
3	*Echinochloa colona* (L.) Link	Poaceae	Annuals
4	*Leptochloa chinensis* (L.) Nees	Poaceae	Annuals
B.	Sedges		
1	*Cyperus rotundus* L.	Cyperaceae	Perennials
C.	Broadleaf		
1	*Eclipta alba* (L.) Hassk	Asteraceae	Annuals
2	*Rorippa indica* (L.) Hiern	Brassicaceae	Annuals
3	*Portulaca oleracea* L.	Portulacaceae	Annuals
4	*Physalis angulata* L.	Solanaceae	Annuals
5	*Alternanthera* (L.) DC	Amaranthaceae	Annuals





Note: Columns with the same letter within each treatment are not significantly different at P> 0.05.
D1, D2, D3, and D4: planting density at 79,365; 92,593; 111,111; and 138,889 plants ha^{-1}, respectively.
HW, HW1, and HW2: no weeding, hand weeding once, and hand weeding twice, respectively.

Figure 1. Effects of plant density (a) and hand weeding (b) on weed density

At the 3-4 leaf stage of vegetable corn, weed density was not significantly influenced (*P*≤ 0.05) by the interacting effects of plant density and hand weeding. However, there were significant differences in weed density among the combination treatments at the 8-9 leaf stage and the harvest stage of vegetable corn (**Table 2**). The combination of the higher plant densities (111,111 and 138,889 plants ha^{-1}) and hand weeding once or twice resulted in lower weed density compared to the combination of the lowest plant density (79,365 plants ha^{-1}) and no weeding. The results suggested that higher plant density combined with hand weeding increased weed suppression.

Weed dry mass

Figure 2 presents the effects of plant density and hand weeding on weed dry weight at the harvest stage of vegetable corn. The results showed that weed dry weight differed significantly ($P \leq 0.05$) amongst the plant density treatments as well as hand weeding treatments. The higher plant densities had a lower weed dry weight compared to the lowest plant density. The results were consistent with the work of Ahmed *et al*. (2014) that weed dry weight decreased significantly with an increase in the seedling rate of crop. In terms of hand weeding treatment, there was a significant difference in weed dry weight between weedy check and hand weeding. Hand weeding once and twice significantly decreased weed dry weight in comparison with the weedy check. Similar findings were presented in the study of Vu & Ha (2015). In addition, the ANOVA analysis showed significant two-way interactions between plant density and hand weeding on weed dry weight (**Table 1**). Weed dry weight was the lowest at the combination of higher plant densities and hand weeding twice.

Weed control efficiency (WCE)

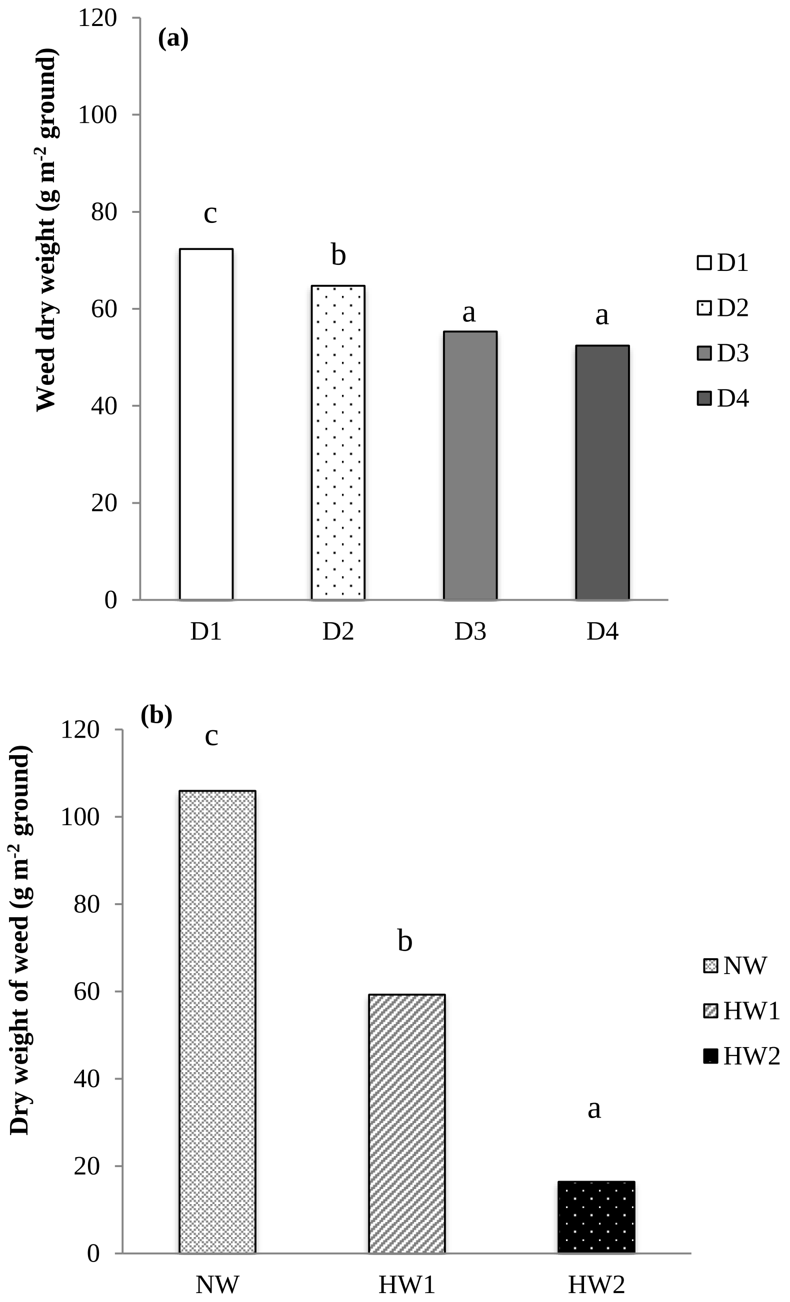
The efficiency of treatments on the control of weeds in terms of dry weight in comparison with the control plot is shown in **Table 2**. The adoption of different plant densities and hand weeding controlled the weed efficiency as evident from the weed control efficiency, which ranged from 40.7 to 86.2%. Weed control efficiency (WCE) increased under hand weeding twice in comparison with hand weeding once, regardless of plant densities. In addition, WCE tended to increase with increasing plant density under both hand weeding once and hand weeding twice conditions. These results are in accordance with the findings of Madavi *et al*. (2017) who reported that higher plant density resulted in higher WCE compared to the lower density. Furthermore, the higher WCE was attributed to the lower weed dry weight. A similar finding was reported in the study of Deshpande *et al*. (2006). Moreover, Gnanasoundari (2013) also suggested that more reduction of weed dry weight by reducing the weed density in the treatments resulted in higher WCE.

Leaf area index (LAI) of vegetable corn

Leaf area (LA) is one of the most important growth traits as it influences the capture of solar radiation which is important for the rapid growth of plants (Valentinuz & Tollenaar, 2006). Thus, plant density of corn per unit area may affect the leaf size and its overall canopy closure which may aid in the competitive ability of corn against weeds. Vegetable corn grown at 92,593 plants ha^{-1} and 111,111 plants ha^{-1} had greater LA than 138,889 plants ha^{-1} (data not shown). The smaller LA at the higher plant density was possibly due to the intra-specific competition between the corn plants for growth resources (Murphy *et al.*, 1996). However, in terms of leaf area index (LAI), analysis of the data showed that LAI increased significantly with increasing plant density, which was observed in all measured growth stages of vegetable corn (**Figure 3b**). It was previously shown that increasing plant density significantly increased LAI of maize (Nguyen *et al*., 2009; Timlin *et al*., 2014; Lykhovyd *et al*., 2019; and Han *et al*., 2020). The increased LAI achieved more light interception and photosynthetic assimilation per unit land area, thus increasing maize biomass yield (Xu, 2018).

In terms of hand weeding, there was no significant difference in LAI between weedy check and hand weeding plots at the 7-9 leaf stage of vegetable corn (**Figure 3a**). However, at the other measured stages, there was a significant difference in LAI between weedy check and hand weeding. The highest LAI was found in hand weeding twice and the lowest LAI was in weedy check condition, but LAI was not significantly different between hand weeding once and hand weeding twice as well as between hand weeding once and weedy check.

The experimental results showed significant differences in the interacting effects of plant density and hand weeding on LAI at all of the observed stages (**Table 3**). At the 7-9 leaf stage of vegetable corn, the highest LAI was obtained from the highest plant density, regardless of hand weeding conditions. However, at both the tasseling stage and harvest stage, the highest LAI value was at the highest plant density combined with hand weeding once and twice treatments (D4HW1 and D4HW2).



Note: Columns with the same letter within each treatment are not significantly different at P> 0.05.
D1, D2, D3, and D4: planting density at 79,365; 92,593; 111,111; and 138,889 plants ha^{-1}, respectively.
HW, HW1, and HW2: no weeding, hand weeding once, and hand weeding twice, respectively.

Figure 2. Effects of plant density (a) and hand weeding (b) on weed dry weight

Dry matter weight of vegetable corn

The results of **Figure 3** and **Table 3** showed that the dry matter weight of vegetable corn increased over time under all treatments. The maximum dry matter weight was observed at the harvest stage (**Figure 3** and **Table 3**).

At the 7-9 leaf stage, there was no significant difference in dry matter weight of vegetable corn between no weeding and hand weeding as well as among different plant densities (**Figure 4**). However, at the tasseling stage and harvest stage, hand weeding once and twice remarkably increased dry matter weight of vegetable corn in comparison with no weeding. The highest dry matter weight of vegetable corn was observed in the hand weeding twice plots at both the above-mentioned growth stages, while the lowest dry matter weight of vegetable corn was found in the no weeding plots. Similarly, in terms of plant density, the dry matter weight of vegetable corn increased significantly with increasing plant density at both of these measured stages. Khan *et al*. (2017) and Han *et al.* (2020) also reported that increasing plant density significantly increased shoot dry biomass of corn, which may be due to the reduced competition from the weeds at the higher densities.

The interacting effects of hand weeding and plant density on dry matter weight of vegetable corn are shown in **Table 3**. There were significant differences in the dry matter weight among the treatments at all of the measured stages. Higher plant density significantly increased the dry matter weight compared to lower plant density, regardless of the hand weeding. The highest plant density combined with hand weeding once and twice had the highest dry matter weight at the tasseling stage and harvest stage.

Yield components and yield of cobs

The results showed that there was no significant difference in the cob weight among plant densities, wheares there was a significant difference in the number of cobs (**Table 4a**). The maximum number of cobs was obtained at the densities of 111,111 and 138,889 plants ha^{-1}, while the minimum number of cobs was observed at the density of 79365 plants ha^{-1}. Therefore, increasing plant density increased the number of cobs, which then led to an increase in cob yield. Higher plant densities (92,593; 111,111 and 138,889 plants ha^{-1}) resulted in significantly higher cob yield compared to the lower plant density (79,365 plants ha^{-1}), but there was an insignificant difference in cob yield between the density of 111,111 and 138,889 plants ha^{-1}. Similar results were observed in the studies of Nguyen *et al*. (2009) and Khan *et al.* (2017). This might be explained by the fact that corn yield can be boosted with increased

Table 2. Effects of plant density and hand weeding on weed density, weed dry weight, and weed control efficiency

Treatment		Weed density (plant m^{-2})			Weed dry weight at the harvest stage (g m^{-2})	Weed control efficiency (%)
		3-4 leaf stage	8-9 leaf stage	Harvest stage		
NW	D1	112.5^{a}	157.4^{b}	192.9^{g}	118.8^{h}	-
	D2	109.3^{a}	160.9^{b}	180.1^{fg}	110.9^{h}	-
	D3	97.6^{a}	140.5^{b}	170.8^{fg}	99.2^{g}	-
	D4	115.5^{a}	136.9^{b}	156.7^{ef}	94.8^{g}	-
HW1	D1	116.2^{a}	105.2^{a}	133.5^{de}	70.5^{f}	40.7
	D2	117.3^{a}	99.8^{a}	128.4^{cde}	62.5^{ef}	43.6
	D3	99.2^{a}	101.1^{a}	112.8^{bcd}	54.1^{de}	45.5
	D4	116.9^{a}	89.5^{a}	96.2^{abc}	49.9^{d}	47.4
HW2	D1	100.1^{a}	102.5^{a}	92.9^{abc}	27.7^{c}	76.7
	D2	114.6^{a}	87.1^{a}	83.3^{ab}	20.9^{bc}	81.2
	D3	112.4^{a}	101.5^{a}	72.1^{ab}	12.7^{ab}	87.2
	D4	110.6^{a}	98.4^{a}	60.9^{a}	12.5^{a}	86.8
$LSD_{0.05}$		16.2	32.5	35.6	8.2	
P		0.138	0.036	0.018	0.021	

Note: Values followed by the same letter in each treatment column are not significantly different at the 5% level. D1, D2, D3, and D4: planting density at 79,365; 92,593; 111,111; and 138,889 plants ha^{-1}, respectively. HW, HW1, and HW2: no weeding, hand weeding once, and hand weeding twice, respectively.

Table 3. Interacting effects of plant density and hand weeding on the physiological traits of vegetable corn

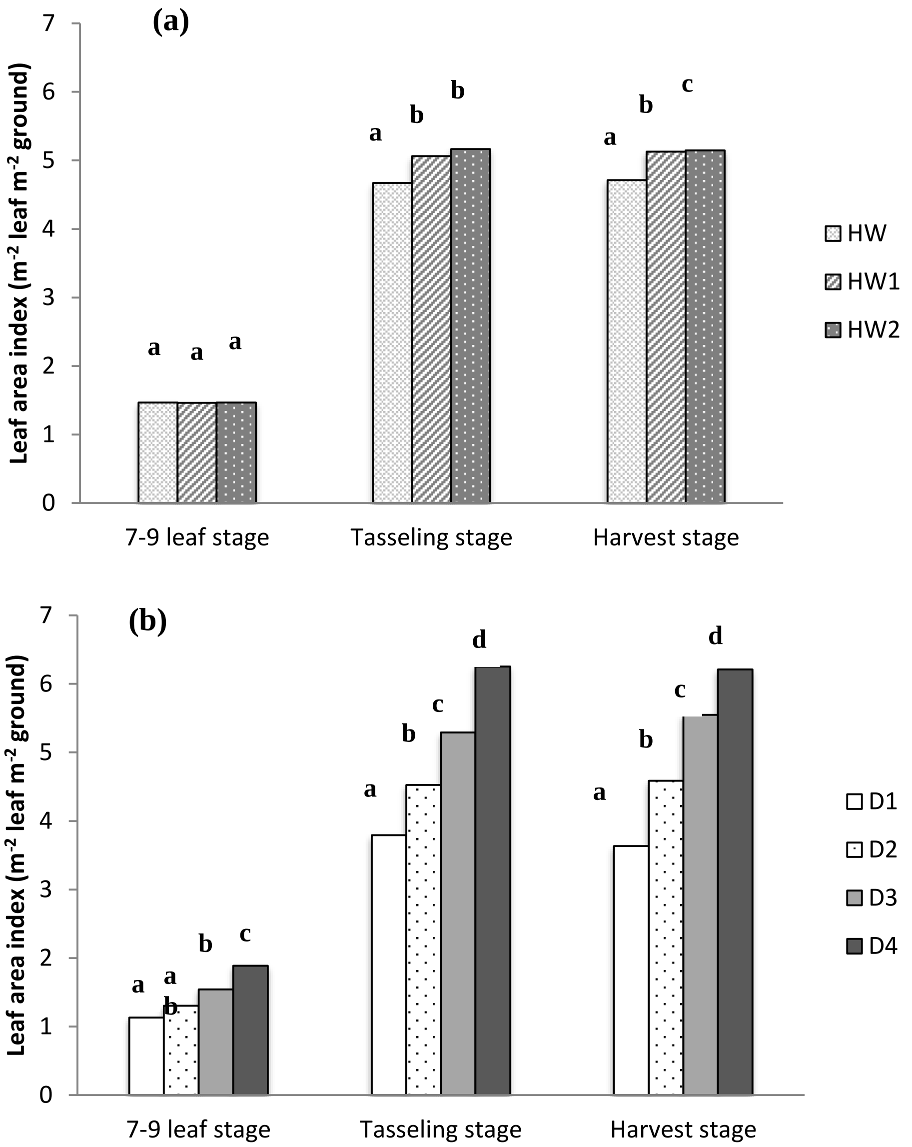
Treatment		LAI			Dry matter weight (g m^{-2} ground)		
		7-9 leaf stage	Tasseling stage	Harvest stage	7-9 leaf stage	Tasseling stage	Harvest stage
NW	D1	1.07^{a}	3.48^{a}	3.56^{a}	46.6^{a}	278.9^{a}	455.8^{a}
	D2	1.29^{ab}	4.28^{cd}	4.28^{b}	53.9^{ab}	335.7^{bc}	497.6^{ab}
	D3	1.57^{b}	4.99^{fg}	5.22^{de}	64.4^{bc}	346.3^{cd}	563.9^{c}
	D4	1.95^{c}	5.93^{ik}	5.8^{f}	77.8^{c}	398.9^{de}	668.6^{de}
HW1	D1	1.15^{a}	3.79^{ab}	3.71^{a}	48.2^{a}	310.5^{ab}	493.8^{a}
	D2	1.28^{ab}	4.56^{de}	4.65^{bc}	55.8^{ab}	355.3^{cd}	566.4^{c}
	D3	1.52^{b}	5.55^{gh}	5.66^{ef}	66.6^{bc}	415.1^{ef}	634.9^{d}
	D4	1.89^{c}	6.35^{km}	6.49^{g}	75.1^{c}	496.2^{g}	735.3^{f}
HW2	D1	1.17^{a}	4.11^{bc}	3.63^{a}	45.8^{a}	326.3^{abc}	558.5^{bc}
	D2	1.34^{ab}	4.74^{ef}	4.84^{cd}	54.9^{ab}	383.2^{de}	635.2^{d}
	D3	1.54^{b}	5.33^{hi}	5.77^{f}	65.5^{bc}	434.0^{f}	711.5^{ef}
	D4	1.82^{bc}	6.49^{m}	6.35^{g}	76.5^{c}	501.8^{g}	767.3^{f}
$LSD_{0.05}$		0.31	0.45	0.53	13.6	40.3	64.6
P		0.046	0.031	0.041	0.037	0.028	0.034

Note: Values followed by the same letter in each treatment column are not significantly different at P> 0.05.
D1, D2, D3, and D4: planting density at 79,365; 92,593; 111,111; and 138,889 plants ha^{-1}, respectively.
HW, HW1, and HW2: no weeding, hand weeding once, and hand weeding twice, respectively.

planting density, however the excessive density can also cause yield loss due to intra-specific competition (Shapiro & Wortmann, 2006). In addition, Matta *et al*. (1990) reported that moderately high densities may be useful to minimize intraspecific competition between the crop plants and wisely suppress weeds to achieve higher grain production.

Similar results in terms of the effects of hand weeding were observed for the number of cobs, cob weight, and cob yield. Hand weeding once and twice remarkably increased cob yield in comparison with no weeding; however, there was no significant difference in cob yield between hand weeding once and hand weeding twice.

Statistical analysis showed significant effects of plant density and hand weeding on the number of cobs and cob yield. There were also significant two-way interactions between plant density and hand weeding on the examined traits (**Table 4b**). The maximum number of cobs was observed in the plots with the density of 138,889 plants ha^{-1} combined with one and two hand weeding treatments and was followed by the density of 111,111 plants ha^{-1} combined with one and two hand weeding treatments, whereas the minimum number of cobs was noted in the lowest plant density combined with no weeding treatment. There was no significant difference in the cob weight among treatments, but there was a significant difference in the number of cobs, which led to the significant effect of all examined treatments on cob yield ($P \leq 0.05$). The cob yield was the lowest at the density of 79,365 plants ha^{-1} combined with no weeding treatment (1.35 tons ha^{-1}) and the highest at the density of 111,111 plants ha^{-1} combined with hand weeding twice (2.23 tons ha^{-1}) treatments. However, there was no significant difference in cob yield among the density of 111,111 and 138,889 plants ha^{-1} combined with hand weeding once and twice (D3HW1, D4HW1, D3HW2, and D4HW2, respectively). The results suggested that, to decrease the labour in manual weeding, the vegetable corn should be planted at the density of 111,111 plant ha^{-1} combined with hand weeding once, which led to an increase in the cob yield due to the suppression of the growth of weeds.

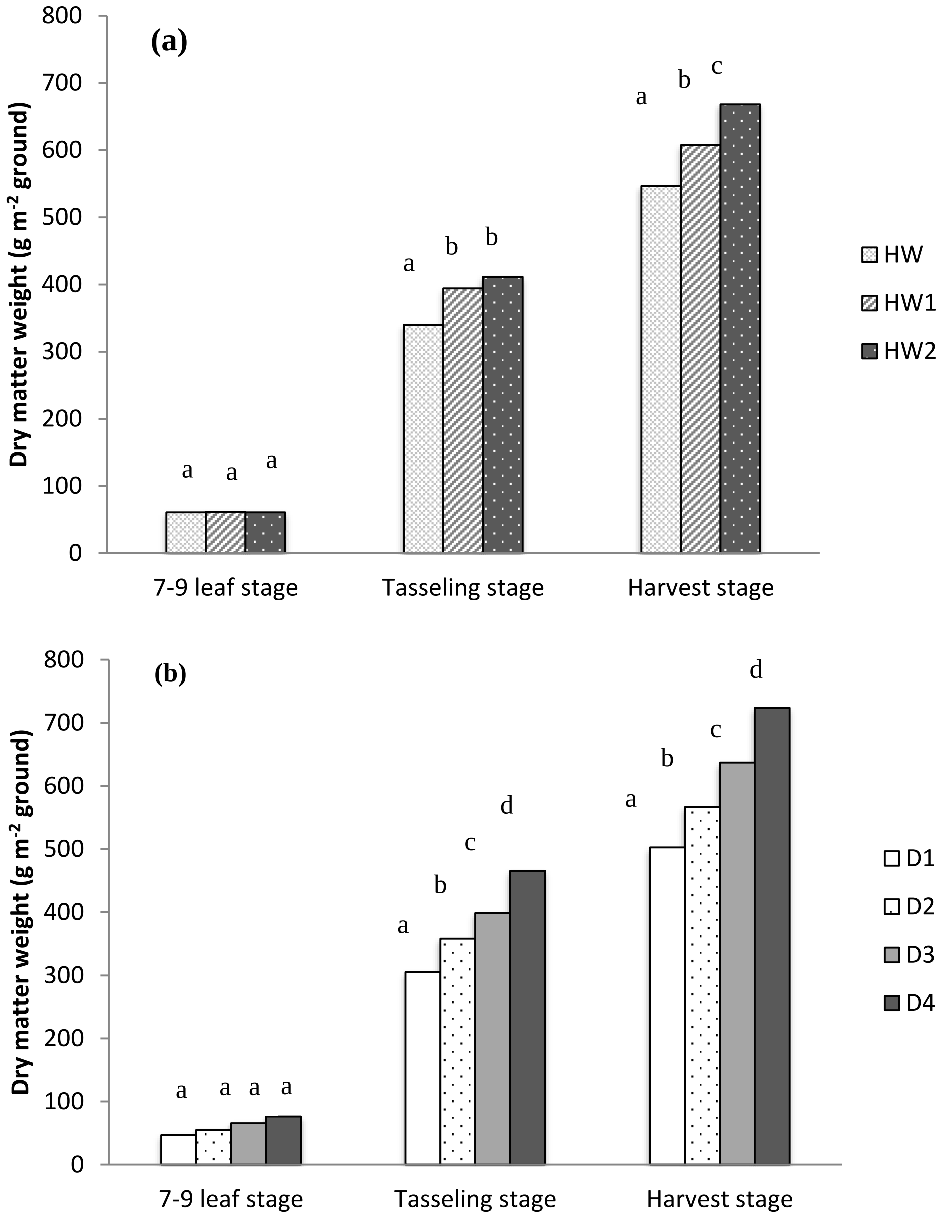


Note: Columns with the same letter within each treatment are not significantly different at $P > 0.05$.
D1, D2, D3, and D4: planting density at 79,365; 92,593; 111,111; and 138,889 plants ha^{-1}, respectively.
HW, HW1, and HW2: no weeding, hand weeding once, and hand weeding twice, respectively.

Figure 3. Effects of plant density (a) and hand weeding (b) on the leaf area index of vegetable corn

Green biomass

Table 4a presents the effects of plant density and hand weeding on the green biomass of vegetable corn. The results showed that green biomass differed significantly ($P \leq 0.05$) among the plant density treatments as well as hand weeding treatments. The higher plant densities had higher green biomass compared to the lowest plant density. Similar results were observed in the studies of Nguyen *et al*. (2009) who indicated that increasing plant density significantly increased green fodder yield for all of the hybrid vegetable corns examined. In terms of hand weeding treatment, there was a significant difference in green biomass between weedy check and hand weeding. Hand weeding once and twice significantly increased green biomass compared to the weedy check. However, there was no significant difference in green biomass between hand weeding once and twice. The result of ANOVA analysis showed



Note: Columns with the same letter within each treatment are not significantly different at P> 0.05.
D1, D2, D3, and D4: planting density at 79,365; 92,593; 111,111; and 138,889 plants ha^{-1}, respectively.
HW, HW1, and HW2: no weeding, hand weeding once, and hand weeding twice, respectively.

Figure 4. Effects of plant density (a) and hand weeding (b) on the dry matter weight of vegetable corn

significant two-way interactions between plant density and hand weeding on green biomass (**Table 4b**). The maximum green biomass was observed in the plots with the density of 138,889 plants ha^{-1} combined with one and two hand weeding treatments (32.22 and 32.36 tons ha^{-1}, respectively), whereas the minimum green biomass was noted in the lowest plant density combined with no weeding treatment (18.78 tons ha^{-1}).

Conclusions

The results showed that increasing the plant density combined with hand weeding once and twice suppressed the growth of weed, which then led to an increase in the yield of vegetable corn.

Table 4a. Effects of plant density and hand weeding on yield components, cob yield, and green biomass of vegetable corn

Treatment		Number of cobs (1000 cobs ha^{-1})	Cob weight* (g cob^{-1})	Cob yield* (tons ha^{-1})	Green biomass (tons ha^{-1})
Hand weeding	NW	270.19^{a}	10.0^{a}	1.53^{a}	23.92^{a}
	HW1	320.86^{b}	10.2^{a}	1.83^{b}	25.94^{ab}
	HW2	320.39^{b}	10.2^{a}	1.99^{b}	26.42^{b}
$LSD_{0.05}$		41.9	1.5	0.18	2.45
P		0.043	0.132	0.043	0.034
Density	D1	225.39^{a}	9.7^{a}	1.48^{a}	19.67^{a}
	D2	277.16^{b}	9.7^{a}	1.72^{b}	23.07^{b}
	D3	336.29^{c}	10.3^{a}	1.95^{c}	26.98^{c}
	D4	376.39^{c}	10.8^{a}	1.99^{c}	31.98^{d}
$LSD_{0.05}$		43.5	2.2	0.21	2.79
P		0.031	0.092	0.041	0.023

*Note: Values followed by the same letter in each treatment column are not significantly different at P> 0.05; * Cob weight and yield were determined after husk removal.*

Table 4b. Interacting effects of plant density and hand weeding on yield components, cob yield, and green biomass of vegetable corn

Treatment		Number of cobs (1000 cobs ha^{-1})	Cob weight* (g cob^{-1})	Cob yield* (tons ha^{-1})	Green biomass (tons ha^{-1})
Hand weeding	Density				
NW	D1	196.03^{a}	9.5^{a}	1.35^{a}	18.78^{a}
	D2	255.56^{bc}	9.8^{a}	1.47^{ab}	22.96^{bc}
	D3	294.44^{cd}	9.8^{a}	1.61^{bc}	25.67^{de}
	D4	334.72^{de}	9.4^{a}	1.69^{bc}	29.28^{fg}
HW1	D1	244.44^{b}	9.8^{a}	1.47^{ab}	19.78^{ab}
	D2	281.48^{bc}	10.1^{a}	1.71^{c}	22.97^{cd}
	D3	358.89^{ef}	10.7^{a}	2.01^{de}	27.66^{ef}
	D4	398.61^{f}	10.2^{a}	2.12^{de}	33.36^{g}
HW2	D1	235.71^{ab}	10.2^{a}	1.61^{bc}	20.46^{ab}
	D2	294.45^{cd}	11.2^{a}	1.99^{d}	24.27^{cd}
	D3	355.56^{ef}	10.9^{a}	2.23^{e}	27.63^{ef}
	D4	395.83^{f}	10.2^{a}	2.15^{de}	33.22^{g}
$LSD_{0.05}$		46.5	2.7	0.23	3.04
P		0.042	0.15	0.037	0.023

*Note: Values followed by the same letter in each treatment column are not significantly different at P> 0.05; D1, D2, D3, and D4: planting density at 79,365; 92,593; 111,111; and 138,889 plants ha^{-1}, respectively; HW, HW1, and HW2: no weeding, hand weeding once, and hand weeding twice , respectively; * Cob weight and yield were determined after husk removal.*

The lower weed density and weed dry weight s were found at the higher plant density combined hand weeding twice treatment. Similarly, higher plant density combined with hand weeding resulted in higher cob yield compared to the lowest plant density combined with no weeding treatment. However, there was no significant difference in cob yield among the densities of 111,111 and 138,889 plants ha^{-1} combined with hand weeding once and twice. Therefore, the results suggested that under the lack of manual weeding labour condition, vegetable corn should be planted at the high density of 111,111 plants ha^{-1} combined with hand weeding once at 3-4 leaves, which suppressed the growth of weed and obtained the high cob yield (2.01 tons ha^{-1}).

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