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Full Length Research Paper

Response of cabbage to depth of transplanting, soil amendment and water stress on a Japanese volcanic ash soil

Nsalambi V. Nkongolo[1], Mitate Yamada[2] and Atsushi Yamasaki[3]

[1]Environmental Science Program, Department of Cooperative Research Department of Agriculture, Biology, Chemistry and Physics College of Natural Sciences, Technology and Mathematics and Cooperative Research and Extension Lincoln University of Missouri Jefferson City, MO 65102-0029, U.S.A.

[2]Crop Production and Post harvest Technology Division, Japan International Research Center for Agricultural Sciences (JIRCAS),Tsukuba Science City, Japan 305-8686.

[3]Vegetable Cultivation Technology Systems Laboratory, National Agriculture Research Center, Tsukuba Science City, Japan 305-8666

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Transplants growth may be reduced by environmental factors when appropriate cultural practices are not used. We studied the response of cabbage to depth of transplanting (DT), soil amendment (SA) and water stress (WS) in a volcanic ash soil at the National Agriculture Research Center in Tsukuba Science City, Japan. Two separate experiments were conducted during a six weeks period: in field and in container. Soil amendments consisted of chemical fertilizer (CF) applied as N-P_2O_5-K_2O 14-14-14 at the rate of 143 kg ha^{-1}, no fertilizer (NF) and dried animal manure (AM) applied at the rate of 1111 kg ha^{-1}. An additional treatment for the container experiment consisted of a soil subjected to four years application of animal manure + CF (CAM). Water stress consisted in one (WS_1) and three (WS_2) irrigations per week in the field, and the same irrigation schedule per two weeks in containers. Cabbage was transplanted in three distinct phases: at the top of the root ball (DT_0), the depth of cotyledon leaves (DT_1) and the first true leaf (DT_2). After six of field growth, cabbage total dry mass (TDM) decreased by 43, 39 and 33% in AM, CF and NF respectively when WS_2 was imposed. These results were also confirmed in container study. Animal manure was effective in reducing the severity of the suppressive effect of DT, but not that of WS on cabbage growth. Increase in cabbage overall growth, which was higher in CF and CAM as compared to AM and NF, was mainly due to nutrient supply.

Key words: Animal manure, chemical fertilizer, cabbage growth, transplants.

INTRODUCTION

In Japan, transplantation is widely used in the production of various field and container-grown vegetable and ornamental crops. This planting method is advantageous since it enables a precise environmental control during the critical stages of germination and early seedling. However, after field or container establishment, trans-plants growth may be reduced by many environmental stresses, especially when appropriate cultural practices are not used. Several authors have investigated the effect of cultural practices on the growth and yield of transplanted crops. Bucan et al. (2005) studied the effect of transplant age and type, on the growth and yield of the seed propagated globe artichoke cv. Talpiot. Transplants were 81, 68 and 51 days old, and all were grown in same size pots. Three months after planting, plants developed from 81-day old transplants were significantly higher and of the larger rosette diameter compared to those developed from 51-day old transplants. However, seven months after transplanting, this difference was no longer present. Lamont (1992) reported that transplant age had little effect on broccoli (*Brassicae oleracea* var. *italica*) head weight and diameter. Ten years earlier, Kratky et al. (1982) studied the effect of container size, transplant age, and plant spacing on Chinese cabbage. They found that seedlings from larger containers probably performed bet-

*Corresponding author. E-mail: nkongolo@lincolnu.edu

ter as a result of more favorable physical properties or fertilization stress of the container media. Transplant age affected maturity time minimally and did not affect yield. Cabbage head weight increased with decreasing plant density. Knavel and Herron (1981) studied the influence of tillage systems, transplant spacing and nitrogen on head weight, yield and nutrient concentration of spring cabbage. They found that spring cabbage plants grown by no-tillage culture yielded less than conventional tilled plant when grown under the same nitrogen treatment and spacing. Hanna et al. (1997) studied the yield of heat-tolerant tomatoes with deep transplanting, morning irrigation and white mulch. They found that transplanting tomatoes to a depth of 15.0 cm significantly increased marketable yield in two years and the total yield in a single year study. Vavrina et al. (1996) reported that deeper transplanting of tomatoes increased first harvest yield. Vavrina et al. (1994) also indicated that bell pepper (*Capsicum annum* L) transplants set to the depth of cotyledon leaves or to the first true leaf yielded more fruit than transplants set to the top of the root ball (root-shoot interface). For cabbage, which is among the top three vegetables of interest in Japan, there are only few studies where the depth of transplantation has been investigated among its currently used cultural practices. Fujiwara et al. (1998) studied the effect of transplanting depth on yield and uniformity of head size. They found that cabbage transplanted in the soil covered root ball had better survival rate, larger leaf area, grew faster and were about 1.5 times heavier and more uniform than were those from the exposed root ball plots. Fujiwara et al. (1998) also tested the effect of root ball moisture content at the time of transplanting on cabbage transplants establishment and growth. They found that primary growth of cabbage seedlings was improved and hastened by maintaining high root ball moisture. In the Tsukuba area, the best time for growing cabbage is between August and December (Kunio, 1979). The transplanting period is therefore characterized by high temperature in summer and dryness in winter, sometimes abundant rainfall by typhoon in autumn (Hanada, 1990; Hideyuki, 2000). The depth of transplantation is here of utmost importance because seedlings superficially transplanted may dry up or be washed out by water erosion. This period is also characterized by high rate of evaporation and soil sealing, crusting and cracking phenomena are sometimes encountered. Although soil moisture level may be adequate in deeper soil layers, the surface layer often dries rapidly and may restrict water exchange. The lack of moisture in upper soil layer results in poor transplants establishment. Seedlings transplanted too deeply may also be faced with excessive water and fungi problems. The search for appropriate cultural practices to deal with these environmental conditions is therefore a necessity. The objective of this experiment was to study the response of cabbage to depth of transplanting and excessive water in the presence of animal manure and chemical fertilizer.

MATERIALS AND METHODS

Field experiment

The study was conducted on a volcanic ash soil at the National Agriculture Research Center, Tsukuba (Japan). The soil of the experiment site is known as a 'light-colored Kuroboku' (MAFF, 1992). Soil preparation consisted in plowing to a depth of 0.15 to 0.20 m. The study field was 30 m long by 5 m large and was divided into three main plots of 50 m^2 each. The experiment design was a 3 x 2 x 3 factorial in a split -plot arrangement replicated nine times for a total of 162 plants. The three factors were:

- soil amendment (SA) with three levels: no-fertilizer (NF), chemical fertilizer (CF) and dried animal manure (AM);
- Water stress (WS) with two levels: one irrigation (WS_1) and three irrigations (WS_2) per week;
- Depth of transplantation (DT) with three levels:
  - The top of the root ball which is the usual transplanting depth in the Tsukuba area (DT_0).
  - The depth of cotyledon leaves (DT_1).
  - The first true leaf (DT_2).

SA made the main plots while WS and DT were in the subplots. Fifty four plants or 3 replicates of the experiment (3 x 2 x 3 x 3 rep.) were harvested every two weeks for the six weeks experiment. N, P_2O_5, K_2O 14- 14-14 compound fertilizer was applied at a rate of 143 kg ha^{-1} for CF treatment. AM was applied at a rate of 1111 kg ha^{-1}. Field application was done by uniformly spreading the fertilizers over the plot in a first step, and by incorporating them into soil with a rotary cultivator at 0.15 m depth. Cabbage seeds were sown in plug tray on and transplanted into the field at 0.30 x 0.60 m spacing. Insects control treatment was only applied at transplanting time. Soil moisture was monitored with tensiometers inserted in each plots. At each irrigation cycle, 0.6 liter of water applied individually to each cabbage plant once or three times a week as planned. At the end of every two weeks experimental period, soil physical properties were measured and soil samples taken (data not included). Cabbage plants were thereafter taken with a shovel to get the entire root system. The entire plant was washed and data on root and shoot length, root, shoot and leaf fresh weights and number of leaves were directly recorded. Root, stem and leaves were dried up (at 70^o C) during 72 h and weighted.

Container experiment

The container study was started five days after the field experiment. It was set under a rain shelter with a moving roof at the National Agriculture Research Center, Tsukuba, Japan. Fifty four containers of 0.25 m diameter and 0.30 m height were filled up with soil taken from a field adjacent to our field experiment (soil 1). Eighteen additional containers were filled up with soil taken from a field subjected to four years continuous application of dried animal manure (soil 2) . Containers filled up with soil 1 were divided into three groups of 18 containers each and were amended with AM, CF and NF respectively. Continuously applied animal manure soil (Soil 2) was also amended with CF and made the fourth treatment, i.e. continuously applied animal manure + CF (CAM). The experimental design was a 4 x 2 x 3 factorial in a split-plot arrangement with three replications. Three cabbage plants were transplanted in each container to give a total of 216 plants for the entire container experiment. Seventy two plants or 3 replicates (4 x 2 3 x 3 rep) were harvested every two weeks for the six weeks experiment. As in the field study, SA made the main plot while WS and DT were in the subplots. For CF and CAM treatments, 714 x 10^{-5} kg of N-P_2O_5-K_2O 14-14-14 compound fertilizer was applied per container. For AM, 42255 x 10^{-5} kg of dried animal manure was applied per container. Cabbages were transplanted as in the field experiment at the

Table 1. Effect of depth of transplanting, soil amendment and water stress on cabbage growth after two weeks of field experiment.

Soil Amendment (SA)	RLT (cm)	RDW (g)	SHT (cm)	SDW (g)	LDW (g)	TDM (g)
No Fertilizer (NF)	10.76	0.04	15.23	0.07	0.45	0.57
Chemical Fertilizer (CF)	10.14	0.05	19.18	0.13	0.75	0.93
Animal Manure (AM)	9.17	0.06	16.73	0.09	0.45	0.59
Water Stress (WS)						
WS1 (One irrigation/ week)	10.70	0.05	17.17	0.10	0.58	0.72
WS2 (Two Irrigations/week)	9.35	0.05	16.92	0.09	0.52	0.67
Depth of Transplanting (DT)						
DT0 (Top of rootball)	10.58	0.05	16.87	0.10	0.56	0.71
DT1(Depth of cotyledon)	10.06	0.05	16.72	0.09	0.51	0.65
DT2 (At the first true leaf)	9.43	0.05	17.56	0.09	0.58	0.72

Analysis of variance

Sources of Variation	df	F	P	F	P	F	P	F	P	F	P	F	P
Blocs	2	0.31	0.75	1.21	0.38	0.70	0.55	0.35	0.72	1.29	0.37	1.62	0.31
Soil amendment (SA)	2	0.63	0.58	3.31	0.14	**23.9**	**0.01**	**16.6**	**0.01**	**9.71**	**0.03**	**42.9**	**0.01**
Error (a)	4	18.42		0.0003		2.98		0.0009		0.055		0.008	
Water Stress (WS)	1	**5.17**	**0.03**	0.01	0.92	0.28	0.61	0.06	0.81	1.08	0.31	0.09	0.76
Depth of Transpl. (DT)	2	1.26	0.29	0.32	0.73	1.16	0.33	0.44	0.65	0.61	0.55	0.29	0.75
Interaction													
SA x WS	2	0.55	0.58	0.63	0.54	0.16	0.33	0.96	0.39	3.51	0.04	0.80	0.46
SA x DT	4	0.73	0.58	0.05	0.99	0.51	0.73	0.62	0.65	0.36	0.84	1.09	0.38
WS x DT	2	0.37	0.69	1.89	0.16	0.19	0.82	0.36	0.69	1.25	0.31	2.17	0.13
SA x WS x DT	4	0.73	0.58	0.72	0.58	0.02	0.99	0.11	0.98	0.42	0.79	0.74	0.57
Error (b)	30	4.71		0.042		3.08		0.0005		0.041		0.025	

RLT = root length, RDW = root dry weight, SHT = shoot height, SDW = shoot dry weight, LDW = leaves dry weight, TDM = total plant dry mass.

top of the root ball (DT_0), the depth of cotyledon leaves (DT_1) and the first true leaf (DT_2). Three plants were transplanted into each container, corresponding to each of the three DT. Plants were watered once (WS_1) on Mondays or three (WS_2) times (Monday, Wednesday and Friday) every two weeks at container capacity. Tension-meters were inserted in the middle of each container in each treatment to monitor soil water potential. A theta probe moisture sensor (FDR) was used to measure water content in containers whenever necessary. Pathogens control treatment was applied as the need occurred. At the end of every two weeks experimental period, data on soil physical properties were taken (not included) and immediately after, each container was flooded with water, its soil was carefully melted by hand and the container's bottom hole was thereafter opened to evacuate water and soil. Water was again provided until the root system was completely washed. This method enabled us to easily take plants with the entire root system. Plants were thereafter subjected to measurements as in the field study.

Statistical analyses

All statistical and regression analyses were done using Statistix statistical package (Analytical Software, Tallahasse, FL).

RESULTS

Field experiment

The effect of Depth of transplanting (DT), Water stress (WS) and Soil amendment (SA) on cabbage growth parameters after two weeks of field growth is showed in Table 1. Data for four and six week's experimental periods are showed in Tables 2 and 3, respectively.

Two weeks of field growth

Two weeks after transplanting, cabbage shoot dry height (SHT) and shoot dry weight (SDW), leaf dry weight (LDW) and total dry mass (TDM) were significantly affected by Soil amendment. The highest growth was obtained in plots subjected to chemical fertilizer application (CF) as showed in Table 1. Cabbage root length (RLT) was however significantly reduced in plots subjected to three irrigation times per week (WS_2). Finally, root dry weight (RDW) did not respond to any of the applied treatment. Cabbage overall growth was superior in CF plots as compared to no fertilizer (NF) and animal manure (AM).

Four weeks of field growth

After four weeks of growth in field, all growth parameters studied were significantly affected by soil amendment, except root length. In addition, all growth parameters

Table 2. Effect of depth of transplanting, soil amendment and water stress on cabbage growth after four weeks of field experiment.

Soil Amendment (SA)		RLT (cm)		RDW (g)		SHT (cm)		SDW (g)		LDW (g)		TDM (g)	
No Fertilizer (NF)		17.33		0.15		10.17		0.29		1.68		2.13	
Chemical Fertilizer (CF)		14.83		0.22		12.39		0.86		5.66		6.74	
Animal Manure (AM)		15.61		0.25		11.11		0.59		3.79		4.63	
Water Stress (WS)													
WS1 (One irrigation/ week)		16.67		0.23		10.48		0.65		4.11		4.99	
WS2 (Two Irrigations/week)		15.19		0.18		10.96		0.51		3.31		4.00	
Depth of Transplanting (DT)													
DT0 (Top of rootball)		17.00		0.20		10.67		0.53		3.41		4.14	
DT1(Depth of cotyledon)		14.50		0.20		11.55		0.57		3.66		4.43	
DT2 (At the first true leaf)		16.28		0.22		11.44		0.64		4.07		4.92	
Analysis of variance													
Sources of Variation	**df**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**
Blocs	2	0.01	0.99	0.11	0.89	0.11	0.89	2.83	0.17	0.57	0.61	0.44	0.67
Soil amendment (SA)	2	2.23	0.22	7.24	0.05	13.9	0.02	95.1	0.01	66.5	0.01	66.5	0.01
Error (a)	4	13.24		0.01		1.61		0.02		1.07		1.44	
Water Stress (WS)	1	3.42	0.07	18.1	0.01	3.17	0.09	17.0	0.01	6.08	0.02	4.72	0.04
Depth of Transpl. (DT)	2	3.44	0.05	0.57	0.57	3.69	0.04	3.56	0.04	1.31	0.29	1.10	0.35
Interaction													
SA x WS	2	0.13	0.88	0.91	0.41	2.25	0.12	***4.70***	***0.02***	1.53	0.23	1.32	0.28
SA x DT	4	1.75	0.17	***3.72***	***0.02***	0.97	0.43	1.01	0.42	0.73	0.58	0.66	0.63
WS x DT	2	1.38	0.27	0.24	0.78	0.06	0.94	0.46	0.64	0.86	0.43	0.92	0.41
SA x WS x DT	4	1.28	0.29	2.48	0.07	0.45	0.77	1.88	0.14	1.24	0.32	1.11	0.37
Error (b)	30	8.65		0.0017		1.15		0.02		1.79		2.14	

RLT = root length, RDW = root dry weight, SHT = shoot height, SDW = shoot dry weight, LDW = leaves dry weight, TDM = total plant dry mass

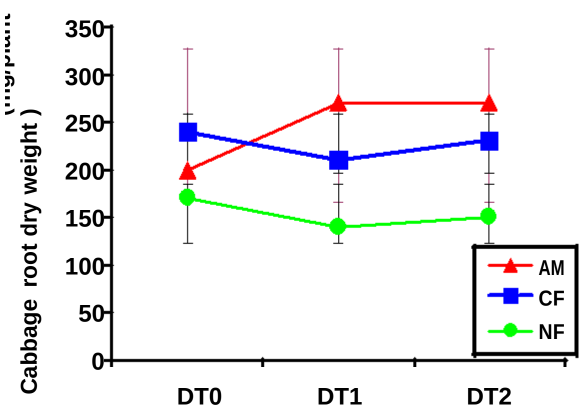

Figure 1. Cabbage root dry weight (RDW) as affected by soil amendment (SA) and depth of transplanting (DT) after four weeks of field experiment. The vertical bars show standard deviation

were also significantly affected by water stress, except root length and shoot height as showed in Table 2. Significant SA x WS and SA x DT interactions were observed for shoot dry weight (SDW) and root dry weight (RDW), respectively. We examined SA x DT interaction for RDW in Figure 1. It shows that on average about 33% of increase in root dry weight by transplanting deeply (DT_1 and DT_2) in animal manure. However, using DT_1 and DT_2 in chemically fertilized plots reduced root dry weight (RDW) of about 17%. RDW grew equally well in CF and AM, but was reduced in NF as well as in plots subjected to WS_2 as it was the case during the first two weeks of study. In addition, RLT was affected significantly by DT. AS for the two weeks growing period, total cabbage growth was superior in CF plots as compared to AM and NF, but with AM superior to NF. In addition, total dry mass (TDM) was reduced in plots subjected to WS_2 as compared to WS_1.

Six weeks of field growth

Table 3 shows the results for six weeks field experiment. After six weeks of field growth, all cabbage growth parameters studied were significantly affected by both soil amendment and water stress, except root length. In contrast, only root length and root dry weight were significantly affected by depth of transplantation. Significant SA x WS interactions were also observed for shoot dry weight (SDW), leaf dry weight (LDW) and total dry mass (TDM). The SA x WS stress for TDM was examined in

Table 3. Effect of depth of transplanting, soil amendment and water stress on cabbage growth after six weeks of field experiment.

Soil Amendment (SA)	RLT (cm)	RDW (g)	SHT (cm)	SDW (g)	LDW (g)	TDM (g)
No Fertilizer (NF)	22.28	0.33	11.33	0.72	4.46	5.50
Chemical Fertilizer (CF)	17.28	0.67	16.89	2.88	18.51	22.06
Animal Manure (AM)	18.89	0.64	15.33	2.03	12.59	15.28
Water Stress (WS)						
WS1 (One irrigation/ week)	19.78	0.67	15.07	2.29	14.86	17.82
WS2 (Two Irrigations/week)	19.19	0.42	13.96	1.47	8.84	10.74
Depth of Transplanting (DT)						
DT0 (Top of rootball)	20.78	0.54	14.33	1.83	11.46	13.83
DT1(Depth of cotyledon)	21.39	0.64	14.39	2.10	13.30	16.04
DT2 (At the first true leaf)	16.28	0.46	14.83	1.71	10.80	12.96

Analysis of variance

Sources of Variation	df	F	P	F	P	F	P	F	P	F	P	F	P
Blocs	2	1.34	0.35	1.98	0.25	2.79	0.17	2.6	0.19	0.45	0.66	0.60	0.59
Soil amendment (SA)	2	1.33	0.36	17.4	0.01	58.7	0.01	51	0.01	**18.9**	**0.01**	**21.1**	**0.01**
Error (a)	4	88.10		0.037		2.52		0.425		59.02		47.39	
Water Stress (WS)	1	0.23	0.63	36.5	0.00	5.91	0.02	25	0.00	**34.3**	**0.00**	**34.2**	**0.00**
Depth of Transpl. (DT)	2	**6.95**	0.01	6.68	0.01	0.48	0.62	2.1	0.14	2.12	0.14	2.30	0.12
Interaction													
SA x WS	2	1.85	0.17	1.82	0.18	0.55	0.58	4.1	0.03	**4.45**	**0.02**	**4.40**	**0.02**
SA x DT	4	0.23	0.92	0.44	0.77	0.63	0.65	0.9	0.50	0.95	0.45	0.94	0.45
WS x DT	2	0.15	0.86	0.16	0.85	*3.33*	*0.05*	0.9	0.39	0.95	0.40	0.93	0.41
SA x WS x DT	4	0.12	0.97	0.18	0.94	1.31	0.28	0.8	0.54	1.26	0.31	1.17	0.34
Error (b)	30	20.18		0.024		2.81		0.353		19.75		14.26	

RLT = root length, RDW = root dry weight, SHT = shoot height, SDW = shoot dry weight, LDW = leaves dry weight, TDM = total plant dry mass

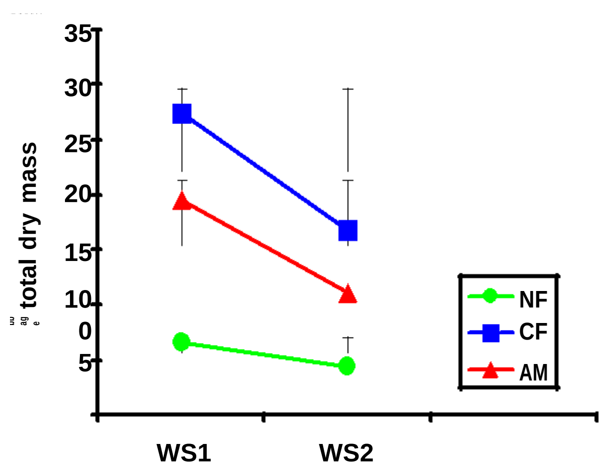

Figure 2. Cabbage total dry mass (TDM) as affected by soil amendment and water stress after six weeks of field experiment

Figure 2. It showed that TDM decreased of about 43, 39 and 33 % in AM, CF and NF respectively with increasing irrigation frequencies (WS_2). An additional WS x DT interaction was also found for SHT. We examined the WS x DT interaction in Figure 3. It showed that SHT responded equally to both WS levels when transplanting was done superficially. However, SHT increased of 12% when cabbage was transplanted deeply (DT_2) in drier plots (WS_1). Finally, SHT decreased of 8% when cabbage was transplanted deeply (DT_2) in wetter plots (WS_2). Based on the above, it is therefore better to transplant deeply in drier field and superficially in irrigated field conditions. Root Length (RLT) of cabbage plants set to DT_0

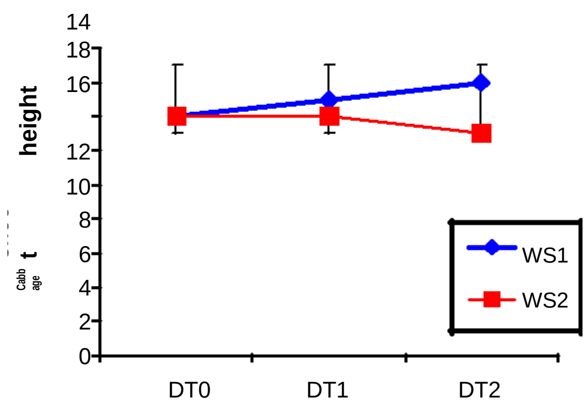

Figure 3. Cabbage shoots height (SHT) as affected by water stress and depth of transplanting (DT) after six weeks in field experiment. The vertical bars show standard deviation.

Table 4. Effect of depth of transplanting, soil amendment and water stress on cabbage growth after two weeks container experiment.

Soil amendment (SA)	RLT (cm)	RDW (g)	SHT (cm)	SDW (g)	LDW (g)	TDM (g)
No Fertilizer (NF)	14.83	0.05	17.33	0.07	0.40	0.52
Chemical Fertilizer (CF)	10.94	0.05	21.33	0.11	0.75	0.91
Animal Manure (AM)	13.06	0.04	16.73	0.06	0.39	0.49
Continuous AM+CF (CAM)	12.57	0.06	20.78	0.12	0.73	0.91
Water Stress (WS)						
WS1 (One irrigation/ 2weeks)	11.86	0.04	19.60	0.09	0.59	0.73
WS2 (Two Irrigations/2weeks)	13.85	0.05	18.49	0.09	0.54	0.68
Depth of Transplanting (DT)						
DT0 (Top of rootball)	11.80	0.05	18.69	0.10	0.58	0.73
DT1(Depth of cotyledon leaves)	14.12	0.05	18.86	0.09	0.57	0.72
DT2 (At the first true leaf)	12.46	0.05	19.58	0.08	0.54	0.67

Analysis of variance													
Sources of Variation		F	P	F	P	F	P	F	P	F	P	F	P
Blocs	2	0.01	0.98	1.28	0.34	0.81	0.49	0.55	0.60	0.29	0.76	0.24	0.79
Soil amendment (SA)	3	1.44	0.32	3.28	0.10	20.3	0.01	68.3	0.01	20.1	0.01	28.8	0.01
Error (a)	6	3.20		0.001		4.81		0.001		0.03		0.35	
Water Stress (WS)	1	3.83	0.06	6.36	0.02	4.59	0.04	0.40	0.53	2.87	0.09	1.53	0.22
Depth of Transpl. (DT)	2	1.62	0.21	0.02	0.98	1.10	0.34	3.70	0.03	0.61	0.55	0.86	0.43
Interaction													
SA x WS	3	2.23	0.10	1.10	0.36	2.75	0.06	1.63	0.20	4.20	0.01	3.64	0.21
SA x DT	6	1.26	0.29	0.35	0.90	0.47	0.82	1.98	0.09	1.25	0.30	1.26	0.29
WS x DT	2	0.40	0.67	0.24	0.78	0.25	0.78	0.40	0.68	2.69	0.08	2.14	1.31
SA x WS x DT	6	1.00	0.44	0.92	0.49	0.52	0.79	1.21	0.32	3.06	0.02	2.59	0.03
Error (b)	40	18.63		0.00		4.87		0.01		0.02		0.03	

RLT = root length, RDW = root dry weight, SHT = shoot height, SDW = shoot dry weight, LDW = leaves dry weight, TDM = total plant dry mass

and DT$_1$ was same, but superior to that of cabbage transplanted deeply (DT$_2$). Root dry weight (RDW) grew equally well in CF and AM plots, but was superior to that of NF. As observed four weeks after transplanting, RDW was severely reduced by WS$_2$. Finally, RDW of cabbage set to DT$_1$ was superior to that of cabbage set to DT$_2$, but equal to DT$_0$. At the end of six weeks of experiment, CF and AM were both equal and superior to NF in increasing TDM. Overall TDM was severely reduced as the result of increasing irrigation frequency.

Container experiment

The effect soil amendment (SA), depth of transplanting (DT), water stress (WS) on cabbage growth parameters after two weeks of container growth is showed in Table 4. Data for four and six weeks experimental periods are showed in Tables 5 and 6, respectively. Figure 4 shows the interaction between soil amendment (SA) and depth of transplanting (DT) for cabbage root length (RTL). The interaction between soil amendment (SA) and water stress (WS) for total dry mass (TDM) is showed in Figure 5.

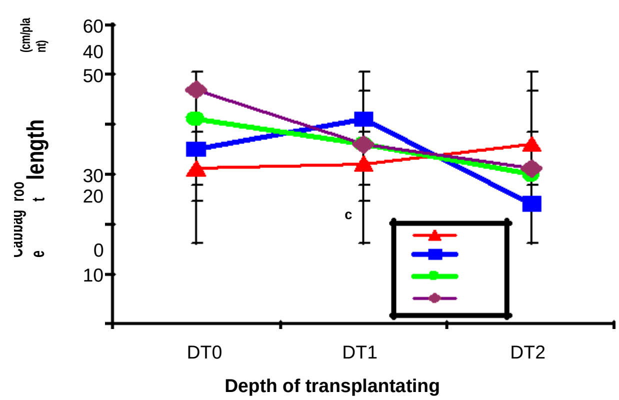

Figure 4. Cabbage root length (RTL) as affected by soil amendment (SA) and depth of transplanting (DT) after four weeks of container experiment. The vertical bars show standard deviation.

Table 5. Effect of depth of transplanting, soil amendment and water stress on cabbage growth after four weeks container experiment.

Soil amendment (SA)		**RLT (cm)**		**RDW (g)**		**SHT (cm)**		**SDW (g)**		**LDW (g)**		**TDM (g)**	
No Fertilizer (NF)		35.67		0.26		11.31		0.23		1.55		1.06	
Chemical Fertilizer (CF)		33.33		0.30		12.89		0.62		4.27		3.35	
Animal Manure (AM)		32.89		0.26		12.06		0.24		1.63		1.13	
nuous AM+CF (CAM)^{y}		37.94		0.44		12.72		0.56		4.21		3.21	
Water Stress (WS)													
WS1 (One irrigation/ 2weeks)		33.25		0.28		13.10		0.44		3.05		2.33	
Two Irrigations/2weeks)		36.67		0.34		11.39		0.38		2.78		2.05	
Depth of Transplanting (DT)													
DT0 (Top of root ball)		38.46		0.35		11.77		0.46		3.27		2.46	
DT1(Depth of cotyledon leaves)		36.17		0.35		12.42		0.41		2.96		2.20	
DT2 (At the first true leaf)		30.25		0.23		12.52		0.37		2.51		1.92	
Analysis of variance													
Sources of Variation	df	F	P	F	P	F	P	F	P	F	P	F	P
Blocs	2	1.31	0.33	0.64	0.56	1.35	0.32	0.08	0.92	2.30	0.18	2.15	0.19
Soil amendment (SA)	3	0.97	0.46	8.73	0.01	1.82	0.24	168	0.01	139	0.01	140	0.01
Error (a)	6	101.05		0.02		5.14		0.05		0.21		0.30	
Water Stress (WS)	1	2.78	0.10	5.72	0.02	14.0	0.01	13.9	0.01	5.49	0.02	3.74	0.06
Depth of Transpl. (DT)	2	5.69	0.01	11.9	0.01	1.10	0.34	11.8	0.01	7.14	0.02	9.40	0.01
Interaction													
SA x WS	3	0.78	0.51	2.59	0.07	1.45	0.24	6.41	0.01	4.53	0.01	3.72	0.02
SA x DT	6	2.84	0.02	1.96	0.09	0.73	0.63	5.88	0.01	4.57	0.01	4.70	0.01
WS x DT	2	1.10	0.34	1.35	0.28	0.90	0.41	0.34	0.71	0.45	0.64	0.58	0.56
SA x WS x DT	6	1.28	0.29	0.89	0.51	0.32	0.92	0.26	0.95	0.96	0.46	0.84	0.55
Error (b)	40	75.62		0.01		3.75		0.05		0.25		0.30	

RLT = root length, RDW = root dry weight, SHT = shoot height, SDW = shoot dry weight, LDW = leaves dry weight, TDM = total plant dry mass

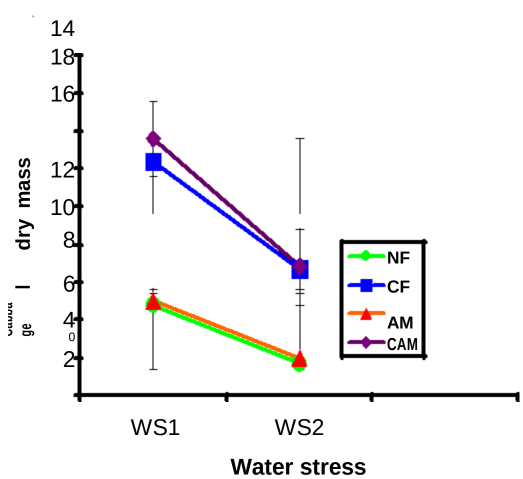

Figure 5. Cabbage total dry mass (TDM) as affected by soil amendment and water stress after six weeks of container experiment.

Two weeks of container growth

After two weeks of growth in container, soil amendment significantly affected shoot height (SHT), shoot dry weight (SDW), leaf dry weight (LDW) and total dry mass (TDM). In addition, root dry weight (RDW) and SHT were affected by water stress while SDW was the only cabbage parameter to be significantly affected by depth of transplanting.

Significant SA x WS x DT interactions were also observed for LDW and TDM. Finally, as for the field study, chemical fertilizer (CF) and continuously applied animal soil + CF (CAM) gave the highest top growth in containers two weeks after transplanting. In addition, cabbage root growth was reduced in wetter containers (WS_2).

Four weeks of container growth

After four weeks of container growth, a similar trend as that observed after four weeks of field growth was found. All cabbage growth parameters were significantly affected by soil amendment and water stress, except root length (RLT) which was only affected by depth of transplanting. In addition, there were SA x WS and SA x DT significant interactions for SDW, LDW, TDM and RLT. We particularly examined SA x DT interaction for RLT in interaction in Figure 4. It shows that RLT in AM containers increased of 17% with increasing DT from DT_0 to DT_2. Increasing DT from DT_0 to DT_2 reduced RLT of 34,

Table 6. Effect of depth of transplanting, soil amendment and water stress on cabbage growth after six weeks container experiment.

Soil amendment (SA)		**RLT (cm)**		**RDW (g)**		**SHT (cm)**		**SDW (g)**		**LDW (g)**		**TDM (g)**	
No Fertilizer (NF)		42.30		0.37		11.56		0.51		3.22		2.33	
Chemical Fertilizer (CF)		34.50		0.62		14.44		1.39		9.56		7.56	
Animal Manure (AM)		41.55		0.40		11.44		0.49		3.23		2.34	
Continuous AM+CF (CAM)[y]		53.93		1.06		13.72		1.42		10.21		7.72	
Water Stress (WS)													
WS1 (One irrigation/ 2weeks)		48.08		0.88		14.11		1.28		8.88		6.72	
WS2 (Two Irrigations/2weeks)		38.06		0.34		11.47		0.63		4.23		3.25	
Depth of Transplanting (DT)													
DT0 (Top of rootball)		44.21		0.68		12.88		0.96		6.65		5.01	
DT1(Depth of cotyledon leaves)		42.69		0.64		12.79		1.00		6.98		5.34	
DT2 (At the first true leaf)		42.30		0.52		12.71		0.90		6.04		4.61	
Analysis of variance													
Sources of Variation	**df**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**
Blocs	2	31.7	0.01	2.41	0.17	3.29	0.11	2.32	0.18	1.87	0.23	2.19	0.19
Soil amendment (SA)	3	104	0.01	55.1	0.01	33.9	0.01	88.2	0.01	90.1	0.01	95.3	0.01
Error (a)	6	11.21		0.03		1.23		0.06		1.86		2.80	
Water Stress (WS)	1	22	0.01	72.3	0.01	80.2	0.01	230	0.01	117	0.01	135	0.01
Depth of Transpl. (DT)	2	0.30	0.74	2.26	0.12	0.11	0.89	1.72	0.19	1.73	0.19	1.91	0.16
Interaction													
SA x WS	3	4.41	0.01	2.99	0.04	0.53	0.66	10.9	0.01	4.71	0.07	5.59	0.01
SA x DT	6	1.69	0.15	0.42	0.86	1.53	0.20	0.57	0.75	0.52	0.79	0.43	0.85
WS x DT	2	0.97	0.39	0.50	0.61	1.10	0.34	5.39	0.01	3.02	0.06	2.83	0.07
SA x WS x DT	6	0.92	0.49	0.64	0.70	1.20	0.33	2.65	0.03	1.37	0.25	1.35	0.26
Error (b)	40	82.02		0.07		1.56		0.03		1.85		2.87	

RLT = root length, RDW = root dry weight, SHT = shoot height, SDW = shoot dry weight, LDW = leaves dry weight, TDM = total plant dry mass

31 and 28% in CAM, CF and NF respectively. This trend is the same to that observed for RDW in the four weeks field experiment. TDM growth was superior but equal in both CF and CAM during the first two weeks of container experiment. This tendency is same as observed in the field experiment. Total dry mass (TDM) responded significantly to SA and DT, but not WS. Also, significant SA x WS and SA x DT interactions prevailed.

Six weeks of container growth

Six weeks after transplanting in containers, SHT, SDW and LDW continued to be affected by SA and WS, but not DT (Table 6). The SA x WS interactions for LDW and SDW persisted, but not the SA x DT one. There were two other significant interactions; WS x DT and SA x WS x DT, for SDW. The WS x DT interaction was examined (Figure omitted) and it showed that in containers subjected to WS_1, SDW increased of 9% with increasing DT from DT $_0$ to DT_2 while using these DT in containers subjected to WS_2 decreased SDW of 29%. These results confirm those obtained in the field experiment. In addition, after six weeks of experiment, the significant effects of SA and WS on RLT and RDW persisted, but not that of DT. Also, significant SA x WS interactions was observed for both root growth parameters. The SA x WS interaction for RLT was examined and it showed that RLT decreased of about 38, 28 and 23% in NF, CF and AM respectively with increasing irrigation frequencies (WS_2). However, RLT remained almost unchanged in CAM applied containers. The interaction also showed that RDW was reduced 63, 71, 62 and 53% in NF, CF, AM and CAM successively in containers subjected to WS_2. TDM still responded to SA and DT but not to WS. In addition, the SA x WS interaction prevailed. We examined this interaction in Figure 5 and it showed that total dry mass (TDM) decreased of 65, 63, 50 and 46% for NF, AM, CAM as the result of increasing irrigation frequencies (WS_2). Even though the same tendency was observed in the field study, reductions in TDM in containers are far higher than those observed in field. This is explained by the fact that in containers, environmental factors were better controlled and therefore the effect of treatment well confirmed.

DISCUSSION

Total dry mass (TDM) was higher in CF as compared to

AM over the entire experimental period in the field. However, in container study, CAM treatment, or the combination between long-term animal manure application and chemical fertilizer gave the best growth. The effect of CAM on cabbage growth parameter is acute for RLT and RDW which respectively increased of 60% and 70% in this treatment as compared to CF (Table 6). Except for soil type used, CAM and CF were made of same amount of N- P_2O_5-K_2O fertilizer. The increase in RLT and RDW observed in CAM can therefore be explained by the improved soil physical properties in this treatment as the result of animal manure application (Nkongolo et al., 2000). All growth parameters investigated in the container study increased with increasing transplanting depth. However this trend was restricted to AM since cabbage growth parameters decreased with increasing depth in NF, CF and CAM treatments. The increase in vegetable crops growth parameters, with increasing depth of transplanting has also been reported by other authors. Vavrina et al. (1994) obtained similar results with pepper while Vavrina et al. (1996) observed that tomatoes transplanted to the depth of the cotyledon leaves yielded more fruit than those transplanted set to the top of the root ball (root-shoot interface). Hanna et al. (1997) found that setting tomato transplants to a depth of 15.0 cm significantly increased marketable yield in both years compared to 7.5 cm depth. The increase of vegetable growth with increasing depth of transplanting has been attributed to many factors. Vavrina et al. (1994) suggested yield increase with deep transplanting were the results of soil temperature amelioration, enhanced fertilizer and water acquisition, and reduced mechanical displacement shock. Hanna et al. (1996) suggested that deep transplanting may have improved root growth due to less fluctuation in moisture and temperature, resulting in a healthier and stronger plant and increased yield. While we agree with these authors, we would add that the increase in cabbage yield in AM amended plots in our study is also the result of improvement in soil physical properties in the root zone as an overall effect. The positive response of RLT and RDW to transplanting depth in the presence of AM was only observed after four weeks experiment in the container study. It was not apparent during the first two weeks and disappeared six weeks of experiment. However, in the field study, this effect was observed only after six weeks. These findings are consistent with data reported by Hanna et al. (1997) who found that deeply planting tomato increased yield in the second (1995), but not the first year (1994) of their study. Vavrina et al. (1996) also noted a dramatic effect of planting depth on tomato during the first harvest. However, the total season yield moderated this effect in later harvests to result in equal yield regardless of planting depth. These results are in agreement with our findings in the container study (Tables 4 and 5) as no significantly different effect of DT was found for all cabbage growth parameters at the end of this experiment. Cabbage growth decreased with increasing water stress (WS_2) in both field and container studies as shown in Figures 2 and 5. Application of AM was effective in reducing the suppressive effect of transplanting depth, but not that of excessive water on cabbage growth.

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