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All Year Round Vegetable Cultivation in Trenches in Cold Arid trans-Himalayan Ladakh

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ABSTRACT

Trench greenhouse is a low cost underground rectangular structure (30'×10'×3'; L×W×D) in north-south orientation with stone wall on four sides. It is covered with polyethylene sheet at ground level during winter months. The air temperature inside the trench was found to be 20.7±2.8 °C warmer during day and 7.0±1.2 °C at night that support growing of leafy vegetables during winter (mid October to early March). Three cycles of crops were grown in a year in the greenhouses as against single crop in open field condition in cold trans-Himalayan Ladakh region. Spinach production was 64 kg -70 kg per trench during mid October to early March. Black plastic mulch significantly increased spinach production during winter months. Vegetable seedlings (13,000 to 39,000 numbers per trench) were raised during late March to early May, which is not possible in open field condition otherwise. A variety of warm-season vegetables were harvested (6 kg - 210 kg per trench) from the trenches during summer months.

Keywords: Food security; Greenhouse; High altitude; Mulching; Solar energy; Trench

1. INTRODUCTION

Trans-Himalayan Ladakh is a unique place in the world where living organisms have to experience conspicuously different environment as compared to their traditional niches. The region is characterised by extreme temperature variations, low precipitation mostly in the form of snow, high wind velocity, sparse plant density, thin atmosphere with high UV-radiation and fragile ecosystem. The average altitude of human habitation in Ladakh is over 3,000 m amsl[1] and the temperature drop up to -30 ºC in winter. Long harsh winters reduce the growing season of fresh vegetables to just three to four months per year. The region is sparsely populated where native human inhabitants have learnt to live with the adverse conditions. However, in past decades, a large number of military troops are being stationed in the region due to the geo strategic nature of the location. High altitude and harsh climatic conditions are the basic environmental challenges while meeting the nutritional requirements for maintaining highest level of mental and physical fitness of the soldiers operating in such adverse conditions are the other critical challenges. Providing essential nutritional support to those operating in high altitude are best taken from resources available locally as timely supply of fresh vegetables from low land is not always possible due to logistics constrains. But a short agriculture season, sub fertile soil, remoteness and the region remaining cut-off for over six months in a year are other inherent constraints. Therefore, meeting the requirement of fresh vegetables for the soldiers and the local populace of the remote mountain areas, especially during winter months is a formidable challenge.

Passive solar greenhouse has played a significant role not only in production of leafy vegetables in sub-zero temperature during winter months but also helped in extending the growing season in Ladakh. The first greenhouse (glasshouse) in Ladakh was established in 1964 at Defence Institute of High Altitude Research (DIHAR), formerly Field Research Laboratory, for growing vegetable during winter months. But soon it was realised that it is difficult to setup a traditional greenhouse in the mountain terrain due to logistics, high cost, and requirement of expertise for installation. To overcome these problems, a low cost passive solar greenhouse, based on trench warfare, was then conceived in late 1960s at DIHAR. Vegetables were grown in trenches covered with polyethylene sheets to save the crops from being frozen during the winter months. The idea worked well and the technology was refined over the years. Construction of trench greenhouse is easy, cheap and do not require much of expertise. Growing vegetables in trenches is now popular as 'Trench Cultivation' among the local farmers and the army in Ladakh sector. Trench greenhouse is now widely recognised as the most economical and easy to establish passive solar greenhouse for Ladakh region[2-6]. Incentives are also being given by the Government for promotion of trench greenhouse in Ladakh due to its usefulness. The increased use of this greenhouse has not only improved dietary intake of vegetables during winter months but also provided an economic opportunity for sale of early season vegetables by the farmers of the region.

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Previous studies have recorded the performance evaluation of leafy vegetables in trench greenhouse during winter months[2-4,7]. But no studies were carried out for cultivation of vegetables throughout the year. Therefore, the objective of the present study was to investigate all year round performance evaluation of trench greenhouse for vegetable cultivation in trans-Himalayan Ladakh. Efforts were made to study the soil and the ambience temperature, and effect of black plastic mulching (BPM) on crop performance during winter months in the greenhouse.

2. MATERIALS AND METHODS

2.1 Study Site and Environmental Conditions

Field experiments on vegetable cultivation and nursery raising in underground trenches were conducted from 2014 to 2016 at an experimental farm of Defence Institute of High Altitude Research in trans-Himalayan Ladakh, India (34°08.3'N; 77°34.3'E, elevation 3344 m). The ambient environmental conditions during the study period at three different cropping seasons were as follow:

Mid October to early March: Mean maximum and minimum temperature was 6.5±2.8 ºC and -7.5±3.4 ºC, respectively. The mean maximum and minimum relative humidity was 35.2±2.2 % and 28.0±2.3 %, respectively. The light intensity at noon was 83883±32266 lux.

Late March to early May: Mean maximum and minimum temperature was 13.4±2.2 ºC and -0.1±2.3 ºC, respectively. The mean maximum and minimum relative humidity was 30.9±1.8 % and 24.5±1.5 %, respectively. The light intensity at noon was 122761±41915 lux.

Mid May early October: Mean maximum and minimum temperature was 20.4±2.3 ºC and 7.4±1.8 ºC, respectively. The mean maximum and minimum relative humidity was 26.8±2.9 % and 21.1±1.4 %, respectively. The light intensity at noon was 120412±28187 lux.

2.2 Description of the Trench Greenhouse

Trench greenhouse is a passive greenhouse for growing vegetables. It is an underground rectangular trench (30' × 10' × 3'; Length × Width × Depth) in north-south orientation with stone wall on four sides (Fig. 1). A furrow (1' 6'' width) is made inside the trench towards the east wall for irrigation. Six to eight plots are made in each trench. Five cylindrical galvanised iron pipes (5 cm dia, 13' long) are placed horizontally in east-west direction at 6 feet gap on top of the trench at ground level to hold the cladding material. UV stabilised 120 GSM Rigidex translucent polyethylene sheet (33' × 13', length × width) is covered on top of the trench during October to May. In harsh winter, a black polyethylene sheet (120 GSM) is placed on top of the translucent cladding material at night to retain heat inside the trench[8]. Stones are placed on edges of the polyethylene to check blowing off the sheet by strong wind. The cladding material is partly open in May and October and fully removed during summer months (June to September) to control the excessive heat build up inside the trench.

2.3 Experimental Design and Treatments

Three cycles of crops were grown each year in 13 trench greenhouses located on a rectangular flat plot during 2014 to 2016. Leafy vegetables were grown during mid October to early March. Vegetable nurseries were raised in the trenches during late March to early May, followed by summer crops during mid May to early October. Data were recorded on crop yield, number of seedlings, air and soil temperature. Air temperature was recorded with a minimum and maximum thermometer (GH Zeal Limited, London). Soil temperature was measured at 10 cm depth using a soil thermometer. The light intensity was measured with a light meter (HD450, Extech Instruments). Chlorophyll was measured with Chlorophyll Meter SPAD-502 (Konica Minolta Sensing Inc., Japan).

Figure 1. Trench greenhouse.

2.4 Growing Leafy Vegetable (mid October to early March)

Spinach (var. Delta) was grown in trenches at 6''×6'' spacing either through direct seed sowing or through root transplanting in mid October. Farm yard manure (FYM) (50 kg), urea (60 g) and DAP (30 g) were applied in each trench at the time of field preparation. Irrigation was done by flooding at 40-50 days interval. Weeding was done once during the growing season. Two harvests were made, first in mid December and second in early March. To study the effect of mulching on crop growth, BPM (30 micron) was laid manually and transplant holes of 5 cm diameter were made at the time of field preparation. To study the effects of colour of additional layer of polyethylene sheet on top of the translucent sheet on the trench during harsh winter, a translucent sheet (120 GSM) was put in place of the black sheet (120 GSM). Effects of directional position within a trench on soil temperature and plant growth was determined by taking measurements on centre of beds each on south, centre and north directions of the north-south oriented trench greenhouse.

2.5 Raising Vegetable Nursery (late March to early May)

Vegetable nurseries of different crops were raised in the trench greenhouse. Seeds were sown in line at 6'' to 8'' gap. FYM (10 kg), urea (60 g) and DAP (30 g) were applied in each trench at the time of field preparation. Irrigation was done by flooding, and one manual weeding was done during the period. Quantity of seed used and number of seedling raised in each trenches were also determined.

2.6 Growing Summer Vegetable (mid May to early October)

A variety of warm-season crops were grown in trenches during summer. FYM (20 kg), urea (60 g) and DAP (30 g) were applied in each trench at the time of field preparation. Second application of urea (60 g) was done at 45 days after transplanting. Irrigation was done by flooding at 5-7 days interval. Manual weeding was done 3-4 times during the cropping season.

3. RESULTS AND DISCUSSION

3.1 Growing Leafy Vegetable in Winter

3.1.1 Air Temperature

The air temperature of outdoor and trench greenhouse is presented in Table 1. The outdoor mean maximum and minimum temperature was 6.5±2.8°C and -7.5±3.4 °C, respectively during mid October to early March. The corresponding temperature inside the trench greenhouse was 27.2±5.6 °C and -0.5±2.3 °C, respectively. Therefore, the air temperature inside the trench was 20.7±2.8 °C warmer during day and 7.0±1.2 °C at night. In comparison, the optimum temperature for spinach growth is 15-20 °C[9].

3.1.1 Soil Temperature:

The soil temperature inside the trench greenhouse is presented in Table 2. The bed position in the trench has significant effect on soil temperature. Beds located on north side of the north-south oriented greenhouse was warmer by 0.9 °C and 1.7 °C than that of centre and south located beds, respectively. Difference in soil temperature within a trench is due to shadowing effect and slow release of heat from the walls during night. BPM increases the soil temperature by 0.3 °C - 0.8 °C.

3.1.3 Crop Growth and Yield

Growth and chlorophyll content of spinach is presented in Table 3. The plant position in the trench has a significant effect on growth related parameters. Plants on north side of the north-south oriented greenhouse showed significantly higher growth than plants on centre and south side of the greenhouse. Slow growth on south side of the greenhouse may be due to the shadowing effect of the trench walls. Shadow cause drop in temperature, which adversely affect crop growth and yield. BPM increased plant growth (Table 3) and yield (Table 4), which could be attributed to higher soil temperature due to the mulch. Root transplanting resulted in significantly higher spinach yield as compared to direct seed sowing (Table 4).

3.1.3 Effect of Colour of Additional Layer of Polyethylene Cover

Colour of additional layer of polyethylene sheet on top of the translucent sheet on the greenhouse at night had a significant effect during harsh winter. Additional layer of translucent sheet had a significant positive effect on soil temperature, plant

Table 1. Mean monthly ambient temperature in open and trench greenhouse and its difference

Month	Open		Trench		Difference (Trench-Open)	
	Max (°C)	Min (°C)	Max (°C)	Min (°C)	Max (°C)	Min (°C)
January	0.7±2.1	-13.3±2.9	18.3±5.1	-4.5±1.9	17.5±3.1	8.7±1.0
February	2.8±3.0	-9.5±3.5	24.3±6.5	-2.3±2.0	21.5±3.5	7.3±1.5
March	7.9±3.3	-5.0±3.5	34.1±4.3	3.5±1.6	26.2±1.0	8.6±1.9
April	12.4±2.0	-0.4±2.3	24.5±2.9	3.1±1.8	12.1±0.8	3.4±0.5
May	16.8±2.5	3.7±1.7	30.1±3.1	6.3±1.7	13.3±0.6	2.6±0.0
October	14.5±3.4	0.2±3.1	27.5±3.7	3.9±0.6	13.0±0.4	3.7±2.5
November	8.8±2.3	-6.6±2.8	26.9±4.7	0.9±4.0	18.1±2.5	7.5±1.2
December	2.6±3.4	-11.3±4.2	23.1±5.5	-3.0±2.4	20.5±2.1	8.3±1.9
Mean	8.3±2.7	-5.3±3.0	26.1±4.5	1.0±2.0	17.8±1.7	6.3±1.3

Values represented as mean ± SD

Table 2. Effect of directional position and black plastic mulch on soil temperature at 10 cm depth in north-south oriented trench greenhouse

Month	Time	Bare soil			Mulch		
		South	Centre	North	South	Centre	North
December	10 AM	2.1±1.4	2.7±1.0	4.0±1.3	3.1±1.4	4.0±1.2	4.6±1.5
	12 PM	3.7±1.2	4.4±1.4	5.8±1.4	4.1±1.4	5.6±1.3	5.9±1.2
	2 PM	5.3±1.4	5.8±1.6	8.1±1.4	5.6±1.3	7.2±1.2	8.2±1.2
	4 PM	6.0±1.5	7.7±1.3	8.4±1.1	6.1±1.5	7.7±1.3	9.1±1.4
January	10 AM	1.0±0.7	1.6±0.9	2.3±1.0	1.6±0.5	2.3±1.0	2.3±1.0
	12 PM	2.1±1.1	2.7±1.1	4.1±1.7	2.2±0.9	3.8±1.5	4.1±1.6
	2 PM	3.8±1.8	4.9±1.8	6.1±1.9	3.8±1.4	5.6±2.1	6.4±2.3
	4 PM	4.6±2.0	5.7±2.1	7.2±2.3	4.7±1.7	6.4±2.0	7.4±2.3
February	10 AM	4.0±1.8	4.5±1.9	5.5±1.3	4.1±1.7	4.9±1.5	5.5±1.6
	12 PM	5.6±1.8	6.3±1.8	7.0±1.7	5.6±1.8	6.8±1.8	7.3±2.0
	2 PM	6.6±1.8	8.0±2.5	8.5±2.3	7.4±2.6	8.4±2.3	8.6±2.4
	4 PM	7.5±2.3	8.5±2.7	9.3±2.9	8.1±2.0	9.0±2.4	9.5±2.7
March	10 AM	7.3±2.2	8.0±2.6	8.5±2.9	7.8±2.5	9.0±2.6	9.0±2.6
	12 PM	9.3±3.5	9.8±3.0	9.8±3.0	9.3±2.5	10.0±2.9	10.0±2.9
	2 PM	11.0±2.8	11.3±3.1	11.3±3.1	11.5±3.4	12.8±3.4	11.8±2.9
	4 PM	11.8±3.2	12.8±3.2	13.0±3.4	12.3±3.6	14.0±3.6	13.3±3.5
Mean		5.7±1.9	6.5±2.0	7.4±2.0	6.1±1.9	7.3±2.0	7.7±2.1

Values represented as mean ± SD

Table 3. Effect of plant position and black plastic mulching on growth and leaf chlorophyll content of spinach (var. Delta) in a north-south oriented trench greenhouse during winter (mid October to early March)

Parameters	DAT*	Bare soil			Mulch		
		South	Centre	North	South	Centre	North
Plant height (cm)	60	11.3±2.3	14.5±3.9	18.2±0.4	13.2±1.8	17.4±1.1	17.8±0.7
	90	14.9±3.6	17.9±4.1	25.5±4.1	15.7±0.7	21.3±1.4	24.8±1.6
	120	20.8±2.8	21.7±5.1	32.0±2.2	22.4±2.4	25.3±2.5	30.6±7.0
No. of leaves	60	4.0±0.0	4.7±0.6	5.0±0.6	4.0±0.6	4.3±0.6	4.7±1.0
	90	5.0±0.0	5.7±0.6	6.7±0.0	5.7±1.0	6.7±0.6	6.9±0.6
	120	6.7±1.5	8.3±1.2	7.3±0.6	7.3±0.6	8.0±1.0	8.7±1.2
Chlorophyll content	60	51.8±8.1	51.3±3.9	53.1±3.8	51.9±0.6	53.3±5.0	49.4±3.9
	90	50.2±7.5	62.8±4.8	59.5±6.1	57.5±5.3	60.7±7.6	58.4±4.1
(SPAD)	120	52.4±0.3	53.9±3.6	54.5±8.2	52.2±2.3	56.4±7.1	57.3±6.6

Values represented as mean ± SD; *DAT: days after transplanting

Table 4. Effect of planting material and black plastic mulching on spinach (var. Delta) production (kg per trench) during mid October to early March

Planting material	Bare soil	Mulch
Root transplanting	64±4	70±5
Seed sowing	31±4	37±3

Values represented as mean ± SD

Table 5. Colour effect of additional layer of polyethylene cover at night during harsh winter on soil temperature, plant growth and yield of spinach (var. Delta)

Parameters	Colour of polyethylene	
	Black	Translucent
[1]Maximum air temperature (°C)	22.3±2.1	24±2.3
[1]Minimum air temperature (°C)	-3.7±0.4	-4.1±0.5
[1]Soil temperature (°C)	4.3±1.4	6.1±1.6
[2]Plant height (cm)	21.7±5.1	34.5±2.4
[2]Number of leaves	8.3±1.2	8.4±0.9
[2]Chlorophyll content (SPAD)	53.9±3.6	60.2±1.8
Spinach yield (kg/trench)	64±4	75±7

[1]Average data of December and January; [2]120 days after transplanting at centre of the greenhouse; Values represented as mean ± SD

growth and overall crop yield as compared to that of the traditionally used black sheet (Table 5). Among other factors, greenhouse with two layers of translucent sheet receives sunlight for extended period in a day. Plants in trench with black sheet cover receive sunlight only when the additional layer is removed manually in the morning.

3.2 Raising of Vegetable Nursery

Seedlings of a variety of crops were raised in the trench greenhouse, which provide early crop production in the region. The outdoor mean maximum and minimum temperature was recorded 13.4±2.2 and -0.1±2.3 °C, respectively, which do not support seedling growth. However, the corresponding temperature inside the trench greenhouse was recorded 29.0±2.6 and 4.9±1.5 °C, respectively. Therefore, the air temperature inside the trench remained 15.6±0.4 °C warmer during day and 5.0±0.8 °C at night from late March to early May. Sale of nursery remains the main source of income from trench greenhouse to a progressive farmer. From a single trench, 13000 to 39000 seedlings were raised depending on the crop (Table 6).

3.3 Growing Summer Vegetable

A variety of vegetables were grown in the trenches (Table 7). Warm-season crops such as cucurbits, tomato, capsicum, brinjal etc are preferred during summer months in the trenches. Growing crops such as capsicum and brinjal in open field condition resulted in low crop productivity in Ladakh condition.

Table 6. Production of vegetable seedlings in trench greenhouse during late March to early May

Crop	Variety	Seed rate per trench (gram)	No. of seedlings per trench
Brinjal	Janak	90	14680±1562
Broccoli	Fiesta	100	15090±1290
Cabbage	Megaton	110	16395±1395
Capsicum	BSS-89	130	14924±1670
Cauliflower	Amazing	100	14520±1321
Chilli	Garima	120	13000±1224
Onion	Lucifer	180	38934±2540
Red Cabbage	Primero	100	16680±1562
Tomato	Tolstoi	80	23632±1610

Values represented as mean ± SD

Table 7. Marketable yield of warm-season crop in trench greenhouse during mid May to early October

Crop	Variety	No. of plants per trench	Marketable yield (kg) per trench
Bottle gourd	Shramik	18	82.2±12.0
Brinjal	Janak	102	41.2±6.2
Capsicum	California Wonder	140	19.1±2.2
Chilli	Saundarya	140	8.0±0.9
Cucumber	BSS-647	32	65.5±7.2
Paprika	KTPL	134	6.0±0.8
Pumpkin	Local selection	18	210.6±40.5
Summer squash	Australian Green	24	170.5±22.6
Tomato	Tolstoi	140	160.4±22.9

Values represented as mean ± SD

4. CONCLUSION

Low cost trench greenhouse was found effective for production of vegetables all year round in cold mountain region. The air temperature inside the trench was 20.7±2.8 °C warmer during day and 7.0±1.2 °C at night that support growing of leafy vegetables in winter. Plastic mulching significantly enhanced crop productivity during winter months. Vegetable seedlings were raised during late March to early May in trench greenhouse, which is not possible in open field conditions otherwise. A variety of warm-season crops were also successfully grown in the trenches during summer months. Change in quantity and quality of light transmitted by greenhouse cladding material is known to influence plant growth and bioactive content. Therefore, further investigations on growth and quality of crops grown under trench are needed.

Conflict of Interest: None

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