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Research Article

Effects of planting configuration and row spacing on growth and production of potato under mulched condition in Dadeldhura, Nepal

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ABSTRACT

An experiment was conducted at the research site of Dadeldhura, Nepal in 2019 to identify optimum plant spacing for potato under mulched condition. Three levels of inter row spacing; 60 cm with single row per bed (1RB), 45 cm with double row per bed (2RB) and 30 cm with triple row per bed (3RB) and intra row spacing (20, 30 and 40 cm) were laid out in factorial randomized complete block design with three replications. Results showed that there was significant difference (p<0.05) for all parameters except on days to 50% germination, 90% flowering, 50% maturity and on main stem number and graded large sized tuber number and it's weight. Growth parameters namely canopy, leaf number and leaf area were significantly higher (p<0.05) in 60 cm (1RB) ×30 cm spacing. Plant height and leaf area index was significantly higher (p<0.05) in 60 cm (1RB) × 20 cm and 30(3RB) ×20 cm spacing respectively. Total number of tubers m^{-2} , weight of tubers m^{-2}, weight of marketable tubers m^{-2}, harvest index, number of small sized tuber m^{-2} ,weight of small sized tubers m^{-2} and weight of medium sized tubers m^{-2} were found to be 56.24%,39.79%, 47.98%,4.41%,90.56%, 113.23% and 70.15% significantly higher (p<0.05) in 30 cm (3RB) compared to 60 cm on (1RB) inter row spacing respectively and 59.72%, 61.15%, 58.30%, 4.41%, 114.90%, 137.31%, 55.39% higher in 20cm compared to 40 cm intra row spacing. Interaction effect was significant (p<0.05) in marketable tuber number and medium sized tuber number in which the average highest number of marketable tubers (134.44) and medium sized tubers (121.08) was found in 30(3RB) ×20 cm spacing which was 165.95% and 235.03% significantly higher compared to 60×40 cm spacing respectively. So, this study showed that 30(3RB) ×20 cm spacing would be best spacing combination under mulched condition.

Keywords: Marketable; unmarketable; medium sized; inter; intra row; leaf area index

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INTRODUCTION

Potato (*Solanum tuberosum*) which is cultivated is highly heterozygous tetraploid (4x = 48) in nature and belongs to Solanaceae family. It is amongst the major food crop to ensure food security. Potato is grown in diverse land types (upland and lowlands), and agro ecological conditions ranging from lowland terai (100masl) to high mountains upto 4000 masl (SARPOD, 2014). It is cultivated in 197,037 hac of land with the production of 258,6287 t and productivity of 13.13 mt/ha (MoAD, 2015). Potato grasps about 6.57 percent of Agriculture Gross Domestic Product (AGDP) and about 2.17 percent of Gross Domestic Product (GDP) of the country (MoF, 2015).. According to the recent statistics (ABPSD, 2015), potato ranks fifth in area coverage and second in quantity of production and first in productivity compared with the main staple food crops of rice, maize, wheat and finger millet grown in Nepal. The importance of potato is increasing day by day due to due to its potentiality and wider adaptability to grow year round in the country. Due to the lack of proper technology and dependency on conventional agriculture, the production of potato is still very low compared to the attainable yield and yield of the neighboring countries like India and China. China has the maximum productivity of potato in the world having more than 40 t/ha (FAO, 2010).

Farmers follow ridge or raised bed with furrow system of plantation in which there is single row per ridge or bed which is the conventional planting system in Nepal. There is also haphazard use of spacing in potato due to which the production has been always under the potential. If the well scientific research can provide them a scientific recommendation about spacing under mulching, it can help them increase their productivity. Various literatures like Endale and Gebremedhin (2001), Gulluoglu and Arrogilu (2009), Sanli *et al*. (2015), Bussan *et al*. (2007), Jamaati *et al*. (2010), Tarkalson *et al*. (2011), Tahmorespour *et al*., (2013) etc had discussed about the effect of different planting configuration and row spacing on yield and yield attributes of potato which findings may not be appropriate for the different soil, environmental and varietal characteristics in context of Nepal. So, research had been done with the objective to determine the optimum plant spacing or population within an unit area by assessing the effects of different planting configuration and row spacing on growth, yield and physical parameters of potato.

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MATERIALS AND METHODS

The details of the materials and methods which were employed during the course of study are described here under.

Description of the study area

The experiment was conducted at the farmer's field located at Bhatkada, Dadeldhura. It was located at co-ordinates of latitude 29.2188° N and longitude 80.4994° E respectively. Dadeldhura had elevation ranging from 333 m to 2639 m above mean sea level (msl).

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Meteorological condition during the experiment

Data regarding meteorological parameters of the studied site like relative humidity, precipitation, maximum and minimum rainfall, bright sunshine was taken from Department of Hydrology and Meteorology, Dadeldhura during the cropping period. The average relative humidity of 54.22 % was found during the experiment. Similarly the average maximum temperature was 23.53^{0}C which ranged from 33.10^{0}C to 13.70^{0}C whereas the average minimum temperature was 12.09^{0}C which ranged from 17.70 ^{0}C to 1.30^{0}C. The average precipitation of 1.09mm with total 100.60 mm rainfall was observed in the experimental field. The average bright sunshine of 8.07 hundredths of an hour with total 742.0 hundredths of an hour was observed in the experimental area. These all parameters indicated that the area was fit for the potato production during the experimental period.

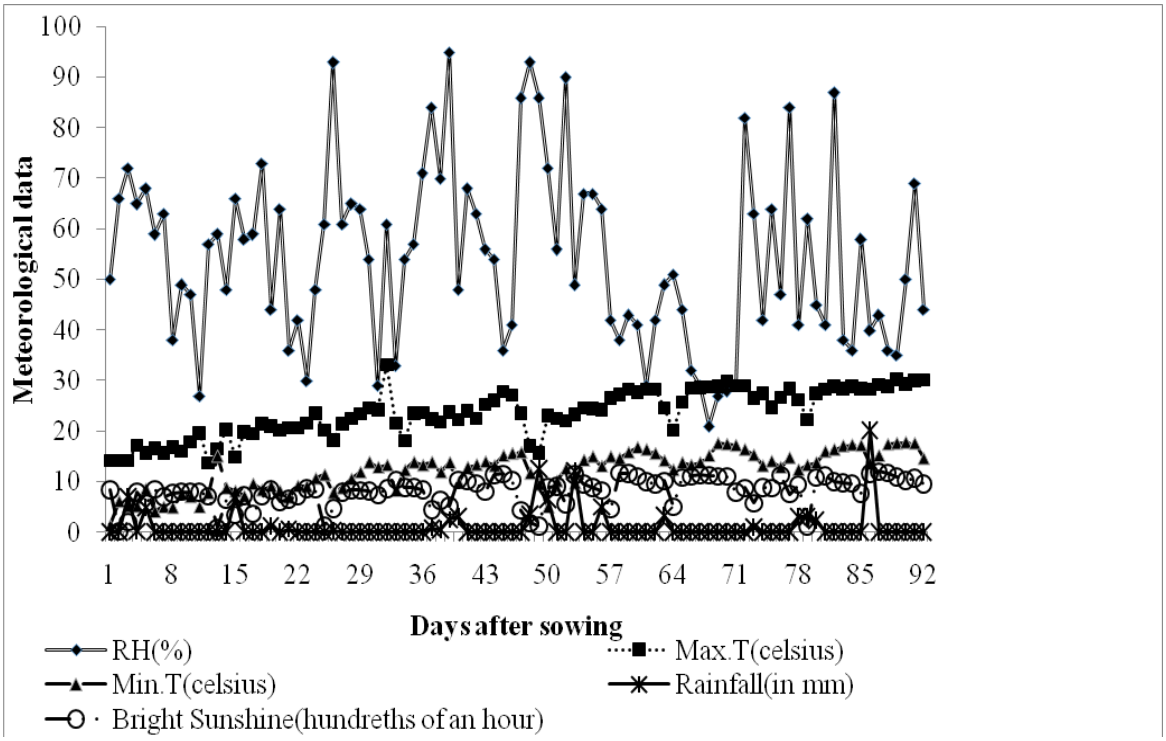

Fig 1: Meteorological condition during the experimental period

Experimental design and Treatment details

The treatments were designed in order to meet the objective i.e. to get the optimum plant population under the black plastic mulch. Considering this, three levels of inter row spacing (60 cm, 45 cm and 30 cm) were designed which can use a standard sized mulch plastic (120 cm in width) in different ways i.e. single, double and triple row of potato is covered with a mulch in case of 60 cm,45 and 30 cm respectively. Three levels of inter row spacing (60 cm with single row per bed (1RB), 45 cm with double rows per bed (2RB), 30 cm with triple rows per bed (3RB) and three levels of intra row spacing (20, 30 and 40 cm) were also designed.The experimental was be conducted in 3×3 Factorial Completely Randomized Block Design (Factorial-RCBD) in 3 replication of each treatment.

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Table 1. Treatments and number of plants per plot and per m^2 for the experimental trial.

Factor 1 (F_1) cm	Factor 2 (F_2) cm	Treatments	Number of plants in a plot	Number of plants per m^2
60(RB)	20	T1=60×20 spacing	60	8.333333
	30	T2=60×30 spacing	40	5.555556
	40	T3=60×40 spacing	30	4.166667
45(2RB)	20	T4=45×20 spacing	80	11.11111
	30	T5=45×30 spacing	52	7.407407
	40	T6=45×40 spacing	40	5.555556
30 (3RB)	20	T7=30×20 spacing	120	16.66667
	30	T8=30×30 spacing	80	11.11111
	40	T9=30×40 spacing	60	8.333333

Each plot is of 3.6×2 m^2 area. So, altogether 27 plots were there for the experimental trail. The details of the treatment are shown below:
Factor 1 (F_1) = Change in inter row spacing (60, 45, 30 cm)
Factor 2 (F_2) = Change in intra row spacing (20, 30, 40 cm)

Layout of the field: Total field area of 22.5× 12.3 m^2 was used as the experimental field in which 9 treatments with 3 replications were laid out. Each plot size was 3.6× 2 m^2 area .The distance between two plots in and between the replication is 50 cm. Randomization of the treatment was done and they were assigned to different plots.

Experimental Procedure

Different following procedures were carried out for different operation involving in potato production from sowing to harvesting of tubers. The soil was made harrowed until completely free of weed roots. About three ploughing, along with the harrowing, was done before the soil would reach a suitable condition: soft, well-drained and well-aerated. Ridge with flat bed and furrow was made on the field and black-silver mulch (silver color on underside) will be used to cover the ridges. Different number of rows were made for different inter row spacing for the optimum coverage of a single mulch so that mulch would be best used. Single, double and triple rows per bed were made for 60, 45 and 30 cm inter row spacing. Planting or sowing of the finely graded cut sized seed (about 40-50 gm per seed) was done. The healthy tuber of Desiree variety which were disease free, well sprouted and from 30-40 gm each in weight were chosen for the seed. Planting was done at the depth of 6-8 inches below the soil on the beds under the mulch. Spacing was maintained according to the treatment assigned to each plot respectively. The recommended doses of fertilizer were manually sprayed in the field before sowing. 30 ton/ha FYM was incorporated into the field about 15 days before plantation. 140 kg/ha Urea, 220kg/ha DAP and 100kg/ha MOP was also applied on the rows before sowing. Due to mulches on the field, all the doses of nitrogen were given as the basal dose at the time of sowing. Potatoes were irrigated in furrow as well as watering through can was be done in the holes made in the mulch. The field was not flooded so that it would not more than 2/3rd height of the ridges. The frequency of irrigation depends on the type of soil, depth of water table and seasonal rainfall. Haulm destruction before harvest was done to reduce damage at harvest. After indicators of tuber maturity like vine death, skin set and desired tuber size, it was harvested after 10-15 days of haulm pulling. After harvesting, they were graded according to their sizes.

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Data Collection

For the evaluation of effect of inter and intra row spacing on potato growth, seed tuber yield and physical quality data were collected for individual response variables from the tagged plants at different times according to the requirement.

After harvesting, tubers were graded into different size based on their diameter using caliper. Each size of tubers will be counted and weighed using sensitive balance to be more accurate.

Growth parameters

Days to 50% emergence – Days to 50% emergence was recorded by counting the number of days from the date of planting to the date at which about 50% of the plants in a plot emerged out.

Days to 90% flowering – Days to flowering was recorded when 50% of the plant population in each plot produced flowers.

Days to 50% physiological maturity – Days to physiological maturity was recorded as days from emergence to maturity when the haulms of 50% of the plant population per plot have showed sign of senescence or turn yellowish.

Plant height (cm) – Plant height was determined by measuring the height of the randomly selected five plants per plot as the distance from the soil surface to the top most growth point of above ground at full flowering (Zelalem et al., 2009).

Number stems (hill^{-1}) – The average number of main stems produced per hill was recorded by counting the main stem s which came out from the seed tuber from five randomly selected plants from each plot at full flowering (Zelalem et al., 2009).

Yield parameters

The number of tubers hill-1, tuber yield hill^{-1}, average tuber weight, average, marketable and unmarketable tuber number m^{-2}, total tuber yield, marketable seed tuber yield and unmarketable tuber yield ton ha^{-1} data will be collected at the time of harvesting from the two middle rows.

Average number of tubers (hill^{-1}) – It is explained as total number of tubers harvested from hills divided by number of plants harvested.

Average tuber yield (kg/hill) – Average weight of total tubers harvested from sampled hills/plants was divided by the number of plants.

Average tuber weight (kg) - It was recorded as the ratio of the weight of tubers per plant/hill to number of tubers per plant/hill which will be expressed in grams at harvest.

Average number of tubers (m^{-2}) - The total number of tubers harvested from net area was counted.

Marketable number of seed tubers (m^{-2}) - At harvesting the tubers harvested from net area was taken from each plot for determination of marketable seed tuber number. In this study marketable tubers include healthy tubers having size categories greater than 25 mm in diameter.

Unmarketable number of tubers (m^{-2}) - Among tubers harvested from net area diseased, rotten, insect attacked, deformed and tubers with diameter less than 25mm will be separated and counted.

Total tuber yield (kg m^{-2}) - Total tuber yield was recorded as the sum of marketable seed tuber and unmarketable tuber yield

Marketable seed tuber yield (kg m^{-2}) - At harvesting the plants harvested from net area was taken from each plot for determining marketable seed tuber yield. In this study marketable tubers will include healthy tubers having size categories greater than 25 mm in diameter

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Unmarketable tuber yield (kg m^{-2}) - Diseased, rotten, insect attacked, deformed tuber and tubers with diameter less than 25mm (non-marketable) was weighed and tabulated

Harvest index (HI) - It was computed by using ratio of oven dry weight of tuber to the total biomass of the plant i.e. oven dry weight of tuber and oven dry weight of haulm.

Physical quality parameters

Tuber size categories (under sized, small, medium and large), was recorded as follows.

Tuber size: Tubers from two central rows will be graded by size of tubers: <10mm (under sized and unmarketable), 10-25 (small) 25-35 (medium) and >35mm (large) by visual method (Fig 2). Tubers in each grade was counted and weighed.

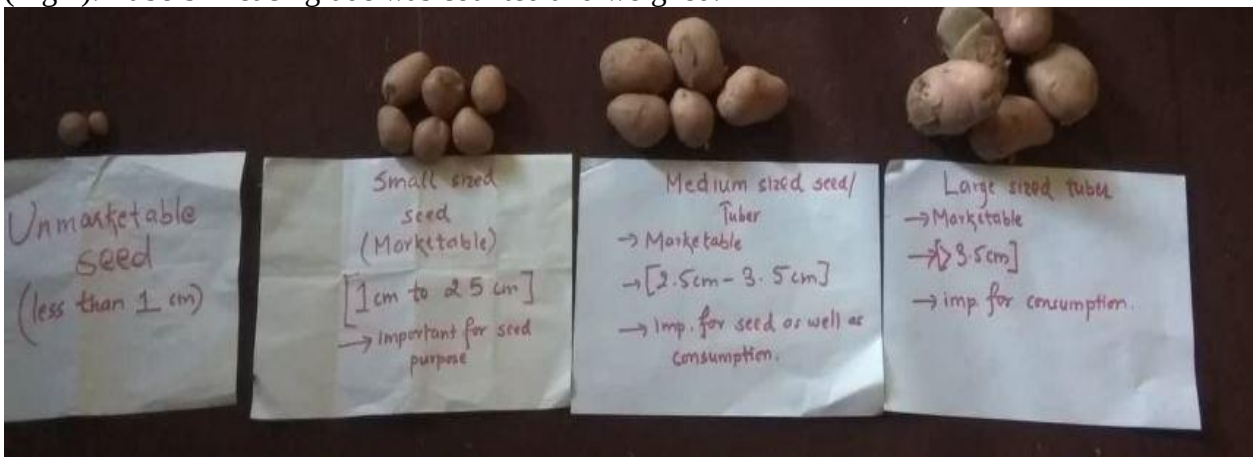

Fig 2: Grading of potatoes into different groups according to their size by visual method

Statistical analysis: The collected data was analyzed by using R-STAT statistical computer package. Analysis of variance (ANOVA) was performed and the significant differences between treatments were determined using least significant difference (LSD) test at probability level of 0.01 or 0.05 where the effects of the treatments were significant at 1% or 5% level of probability, respectively (Dahiru, 2008; Gomez & Gomez, 1984: Sharma *et al*., 2016; Kunwar & Shrestha, 2014; Shrestha, 2019; Kandel & Shrestha, 2019). Graph and tables was constructed by using the MS-excel version 2016 computer software program.

RESULTS AND DISCUSSION

Growth parameters

Days to 90 % germination, 50 % flowering and 90% maturity

The result of analysis of variance showed that there was no any significant difference (P>0.05) by the main and interaction effects of inter and intra row spacing on phenological parameters like Days to 90% germination, 50% flowering and 90% maturity of potato (Table 2). All the treatments took about 30 days, 50days and 90 days for 90% germination, 50% flowering and 90 % maturity respectively.

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Table 2. Effect of different plant configuration and row spacing on growth parameters like germination, flowering and maturity of potato at Dadeldhura, Nepal

Inter row spacing in cm	Days to 90% germination	Days to 50% flowering	Days to 90% maturity
60 (1 RB)	31.80	51.60	90.90
45 (2 RB)	31.75	50.75	91.25
30 (3RB)	31.11	50.11	91.22
SE(±)	0.77	1.11	1.44
$LSD_{0.05}$	ns	ns	ns
F test	ns	ns	ns
Intra row spacing (cm)			
20	31.11	51.11	91.11
30	32.00	50.37	91.37
40	31.60	51.00	90.90
SE(±)	0.77	1.11	1.44
$LSD_{0.05}$	ns	ns	ns
F test	ns	ns	ns
CV (%)	7.37	6.58	4.76

Means followed by the same letter within a column are not significantly different (P > 0.05) from each other, LSD= Least significant difference, CV= Coefficient of variation, ns= non significant, SE (±) = standard error of mean, DAS= Days after sowing, F test is the test for analysis of variance.

Plant height

In case of plant height, the result of F-test showed that there was significant difference (P<0.05) by the main effects of the both inter and intra row spacing on 60 and 70 days after sowing (DAS) while on 45 DAS, there was significant difference (P<0.05) by the only main effect of inter row spacing (Table 3).

Table 3. Effect of different plant configuration and row spacing on plant height and main stem number of potato at Dadeldhura, Nepal

Inter row spacing in cm	Plant height			Main stem number
	45 DAS	60 DAS	75 DAS	
60 (1 RB)	28.86^{a}	33.88^{a}	34.27^{a}	6.177
45 (2 RB)	24.82^{b}	31.11^{ab}	30.63^{b}	6.066
30 (3RB)	25.84^{b}	29.22^{b}	30.30^{b}	5.77
SE(±)	0.89	0.94	0.77	0.544
$LSD_{0.05}$	2.68	2.83	2.32	ns
F test	*	*	**	ns
Intra row spacing (cm)				
20	27.22	33.46^{a}	33.72^{a}	6.22
30	27.17	31.82^{a}	31.47^{ab}	5.77
40	25.13	28.93^{b}	30.01^{b}	6.022
SE(±)	0.89	0.94	0.77	0.544
$LSD_{0.05}$	ns	2.83	2.32	ns
F test	ns	*	*	ns
CV (%)	10.1	9.01	7.3	27.2

*Means followed by the same letter within a column are not significantly different (P > 0.05) from each other, LSD= Least significant difference, CV= Coefficient of variation, ns= non significant, SE (±) = standard error of mean, DAS= Days after sowing, *,** represent significant at 5% and 1% level of significance respectively.*

In case of inter row spacing, highest plant height (28.68 cm at 45 DAS, 33.88cm at 60 DAS

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and 34.27cm at 75 DAS) was found in the highest level of inter row spacing; 60cm which was followed by 45 and 30 cm respectively. But in case of intra row spacing, the highest plant height (33.46cm at 60 DAS and 33.72 cm at 75 DAS) was found in the lowest intra row spacing; 20 cm which was at par with 30 cm and followed by 40 cm.

Number of main stems per hill

There was no any significant difference on both main and interaction effects on main stem number per hill (Table 3). There are about 5-6 number of tillers in all treatments.

Canopy diameter

The analysis of variance revealed that in case of inter row spacing on 45 DAS, the canopy diameter (42.91cm) was found significantly higher ($P<0.05$) in 60 cm which was at par with 45cm and followed by 30cm inter row spacing (Table 4). Similar result was obtained in 60 DAS ($P<0.05$) and 70 DAS ($P<0.01$). In case of intra row spacing, on 45 DAS; there was no any significant effect on canopy diameter. But on 60 DAS, the highest canopy diameter (52.33 cm) significant at $P<0.01$ was found in 40 cm intra row spacing and followed by 30 cm and 20 cm intra row spacing respectively. On 75 DAS, similar result was obtained, i.e. canopy diameter (55.48 cm) was found significantly highest ($P<0.01$) in 40 cm intra row spacing which was at par with 30 cm spacing and followed by 20 cm intra row spacing. There was no any significant interaction effect on canopy diameter.

Number of leaves

The analysis of variance revealed that in case of inter row spacing on 45 DAS, number of leaves was not found significant ($P>0.05$) but on 60 DAS and 75 DAS, number of leaves was found significantly higher ($P<0.001$) in 60 cm which was followed by 45 and 30 cm inter row spacing respectively (Table 4).

Table 4. Effect of different plant configuration and row spacing on number of leaves and canopy diameter of potato at Dadeldhura, Nepal

Inter row spacing(cm)	Number of leaves			Canopy diameter(cm)		
	45 DAS	60 DAS	75 DAS	45 DAS	60 DAS	75 DAS
60 (1 RB)	41.97	54.20^{a}	49.73^{a}	42.91^{a}	48.32^{a}	54.78^{a}
45 (2 RB)	39.00	43.40^{b}	37.48^{b}	40.42^{ab}	48.20^{a}	51.90^{a}
30 (3RB)	38.75	34.71^{c}	28.06^{c}	36.02^{b}	40.51^{b}	45.85^{b}
SE(±)	3.085	2.68	2.88	1.655	2.20	1.68
$LSD_{0.05}$	ns	8.06	8.65	4.96	6.62	5.05
F-test	ns	***	***	*	*	**
Intra row spacing (cm)						
20	43.42	38.091^{b}	32.24^{b}	39.14	41.25^{b}	45.98^{b}
30	37.84	46.00^{ab}	38.60^{ab}	38.37	43.44^{b}	51.06^{a}
40	38.46	48.22^{a}	44.44^{a}	41.83	52.33^{a}	55.48^{a}
SE(±)	3.085	2.68	2.88	1.655	2.20	1.68
$LSD_{0.05}$	ns	8.06	8.65	ns	6.62	5.05
F-test	ns	*	*	ns	**	**
CV (%)	23.2	18.3	22.5	12.5	14.5	9.94

*Means followed by the same letter within a column are not significantly different (P > 0.05) from each other, LSD= Least significant difference, CV= Coefficient of variation, ns= non significant, SE (±) = standard error of mean, DAS= Days after sowing. *, **,*** represent significant at 5%,1% and 0.1% level of significance respectively.*

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In case of intra row spacing, on 45 DAS; there was no any significant effect on number of leaves. But on 60 DAS and 75 DAS, 40 cm intra row spacing had got the significantly highest (P<0.05) number of leaves which was followed by 30 cm and 20 cm intra row spacing respectively. There was no any significant interaction effect on the number of leaves. The findings showed that with increase in space between the plants, there is increase in the shoots and canopy coverage and increase in number of leaves due to more availability of nutrients and sunlight.

Leaf Area

The analysis of variance revealed that in case of inter row spacing on 45 DAS, leaf area was found statistically significant (P<0.01) but on 60 DAS, number of leaves was not found statistically significantly (Table 5). On 45 DAS, the largest leaf area of 2040.73 cm^2 was found in 60 cm spacing which was at par with 45 cm and followed by 30 cm inter row spacing. Similarly, in case of intra row spacing, leaf area was found to be significant (P<0.01) on only 45 DAS in which highest leaf area of 1347.96 cm^2 was found to be in 40 cm followed by 30 cm and 20 cm intra row spacing respectively.

Leaf area index

The analysis of variance revealed that leaf area index was found to be statistically significant (P<0.01) on 45 DAS and significant at P=0.01 at 60 DAS in case of inter row spacing whereas in case of intra row spacing, it was found significant at P<0.05 on 45 DAS and P<0.001 on 60 DAS (Table 5). On 45 DAS, highest leaf area index (1.68) was found in 30 cm followed by 45 cm and 60 cm inter row spacing respectively and in case of intra row spacing, highest leaf area index (1.61) was found in 20 cm which was at par with 30 cm and followed by 40 cm intra row spacing.

Table 5. Effect of different plant configuration and row spacing on leaf area and leaf area index (LAI) of potato at Dadeldhura, Nepal

Inter row spacing(cm)	Leaf Area (cm^2)		Leaf area index(LAI)	
	45 DAS	60 DAS	45 DAS	60 DAS
60 (1 RB)	2040.73(3.31)^{a}	1896.41	1.22^{b}	1.089(0.32)^{b}
45 (2 RB)	1697.24(3.23)^{ab}	2577.14	1.34^{b}	1.818(0.45)^{a}
30 (3RB)	1379.38(3.13)^{b}	1949.61	1.68^{a}	2.090(0.498)^{a}
SE(±)	0.030	331.29	0.091	0.039
$LSD_{0.05}$	0.0918	ns	0.274	0.117
F-test	**	ns	**	*
Intra row spacing (cm)				
20	1347.96(3.13)^{c}	2035.16	1.61^{a}	2.23(0.514)^{a}
30	1697.24(3.23)^{b}	2784.81	1.34^{ab}	2.019(0.481)^{a}
40	2136.96(3.33)^{a}	1603.20	1.28^{b}	0.90(0.283)^{b}
SE(±)	0.030	331.29	0.091	0.039
$LSD_{0.05}$	0.0918	ns	0.274	0.117
F-test	**	ns	*	***
CV (%)	2.84	46.4	19.4	27.5

*Means followed by the same letter within a column are not significantly different (P > 0.05) from each other, LSD= Least significant difference, CV= Coefficient of variation, ns= non significant, SE (±) = standard error of mean, DAS= Days after sowing. The figures inside the parenthesis are the log transformed values (Y= log(x+1)). *, **, *** represent significant at 5%, 1% and 0.1% level of significance respectively.*

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Similarly on 60 DAS, highest leaf area index (2.090) was found in 30cm followed by 45 cm and 60 cm inter row spacing whereas in case of intra row spacing, highest leaf area index (2.23) was found in 20 cm followed by 30 cm and 40 cm intra row spacing. There was no any significant interaction effect between the factors. This finding showed that with decrease in spacing, there is increase in leaf area index.

Yield parameters

Average number of tuber per hill

The analysis of variance revealed that average number of tuber per hill was found to be statistically significant (P<0.01) in case of inter row spacing whereas in case of intra row spacing, it was found significant at P<0.05 (Table 6). The highest average number of tuber per hill (14.55) was found in 60 cm which was at par with 45 cm and followed by 30 cm inter row spacing and in case of intra row spacing, highest average tuber number per hill (14.66) was found in 40 cm which was followed by 30 and 20 cm intra row spacing respectively. There was no any significant interaction effect between the factors. This finding showed that the highest number of tuber per hill was found in wider spacing.

Table 6. Effect of different plant configuration and row spacing on tuber number of potato at Dadeldhura, Nepal

Inter row spacing(cm)	Tuber number			
	Average number of tuber per hill	Average number of tubers per m^2	Marketable tuber number per m^2	Unmarketable tuber number per m^2
60 (1 RB)	14.55^{a}	84.54^{c}	66.00^{c}	16.29(1.21)
45 (2 RB)	13.22^{ab}	106.52^{b}	82.13^{b}	19.95(1.30)
30 (3RB)	11.44^{b}	132.16^{a}	108.95^{a}	20.89(1.32)
SE(±)	0.62	5.58	4.59	0.062
$LSD_{0.05}$	1.86	16.7	13.8	ns
F-test	**	***	***	ns
Intra row spacing (cm)				
20	11.86^{b}	138.27^{a}	107.53^{a}	$28.18(1.14)^{a}$
30	12.69^{b}	98.36^{b}	77.95^{b}	$17.78(1.25)^{b}$
40	14.66^{a}	86.57^{b}	71.60^{b}	$13.48(1.13)^{b}$
SE(±)	0.62	5.58	4.59	0.062
$LSD_{0.05}$	1.86	16.7	13.8	0.188
F-test	*	***	***	0.008
CV (%)	14.2	15.6	16.1	14.7

Means followed by the same letter within a column are not significantly different (P > 0.05) from each other, LSD= Least significant difference, CV= Coefficient of variation, ns= non significant, SE (±) = standard error of mean, DAS= Days after sowing. The figures inside the parenthesis are the log transformed values (Y= log(x)).

Number of tubers per m^2

The analysis of variance revealed that average number of tuber per m^2 was found to be statistically significant (P<0.001) in case of both inter row and intra row spacing (Table 6). The highest number of tuber per m^2 (132.16) was found in 30 cm which was followed by 45 cm and 60 cm inter row spacing respectively and in case of intra row spacing, highest tuber number per m^2 (138.27) was found in 20 cm which was followed by 30 and 40 cm intra row spacing respectively. There was no any significant interaction effect between the factors.

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Number of marketable tubers per m^2

The analysis of variance revealed that average number of marketable tubers per m^2 was found to be statistically significant (P<0.001) in case of both inter row and intra row spacing as well as significant (P<0.05) in the interaction effect of two factors (Table 6 and Fig 3). The highest number of marketable tubers per m^2 (108.95) was found in 30 cm which was followed by 45 cm and 60 cm inter row spacing respectively and in case of intra row spacing, highest marketable tubers number per m^2 (107.53) was found in 20 cm which was followed by 30 and 40 cm intra row spacing respectively. In case of interaction effect, highest number of marketable tubers (134.44) was found in 30×20 spacing which was at par with 45×20 and followed by 30×30,30×40,60×30,60×20,45×30,45×40 and lowest in 60×40 spacing (Fig 3).

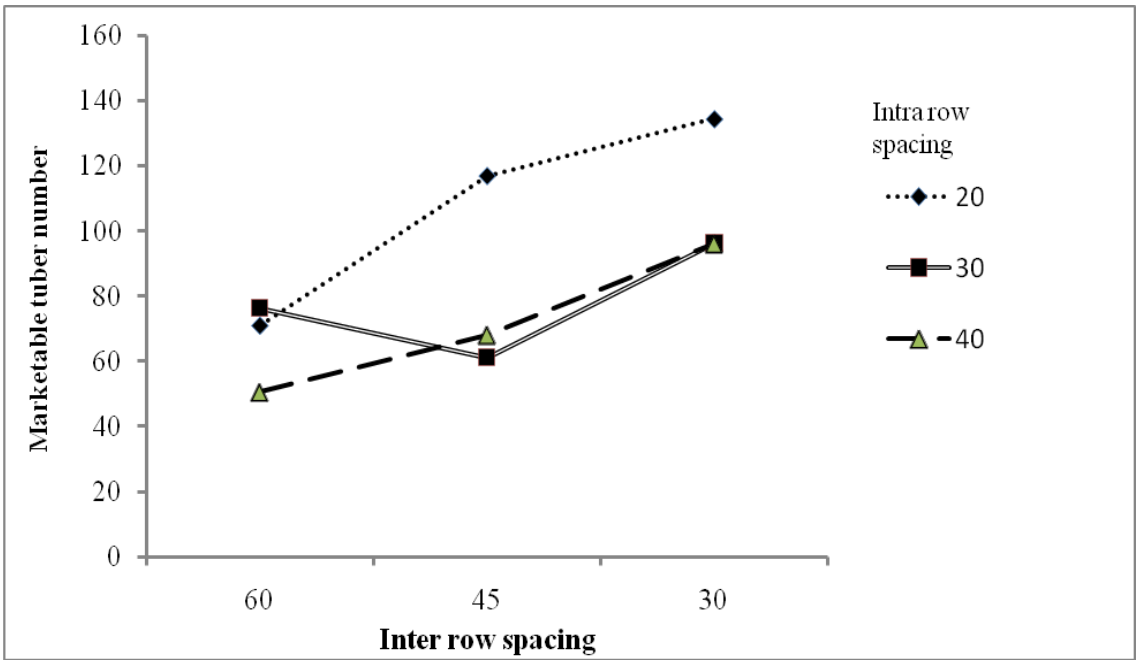

Fig3: Relationship between Inter-Intra row spacing and Marketable tuber number

Number of unmarketable tuber per m^2

The analysis of variance revealed that average number of unmarketable tubers per m^2 was found to be statistically significant (P<0.01) in case of intra row spacing as and non significant in main effects of inter row spacing and interaction effects of two factors (Table 6). The highest average number of unmarketable tubers per m^2 (28.18) was found in 20 cm which was followed by 30 cm and 40 cm intra row spacing respectively. The findings showed that in closer spacing, there is more unmarketable tuber number per m^2 as compared to wider spacing.

Total tuber yield per plant

The analysis of variance revealed that total tuber yield per plant was found to be statistically significant (P<0.001) in main effect of inter row spacing and significant at P<0.05 in main

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effect of intra row spacing (Table 7). The highest total yield per plant (0.67 kg) was found in 60 cm which was followed by 45 cm and 30 cm inter row spacing respectively and in case of intra row spacing, highest total tuber yield per plant (0.61 kg) was found in 40 cm which was at par with 30 and followed by 20 cm intra row spacing. There was no any significant interaction effect between the factors.

Total yield per m^2

The analysis of variance revealed that total tuber yield per m^2 was found to be statistically significant (P<0.01) in main effect of both inter row and intra row spacing (Table 7). The highest total yield per m^2 (5.41 kg) was found in 30 cm which was followed by 45 cm and 60 cm inter row spacing respectively and in case of intra row spacing, highest total tuber yield per m^2 (5.56 kg) was found in 20 cm which was followed by 30 and 40 cm intra row spacing respectively. There was no any significant interaction effect between the factors.

Marketable tuber yield per m^2

The analysis of variance revealed that marketable tubers per m^2 was found to be statistically significant (P<0.01) in case of both inter row and intra row spacing but not significant in the interaction effect of two factors (Table 7). The highest yield of marketable tubers per m^2 (5.15 kg) was found in 30 cm which was followed by 45 cm and 60 cm inter row spacing respectively and in case of intra row spacing, highest yield of marketable tubers per m^2 (5.24 kg) was found in 20 cm which was followed by 30 and 40 cm intra row spacing respectively.

Unmarketable tuber yield per m^2

The analysis of variance revealed that total yield of unmarketable tubers per m^2 was found to be statistically significant (P<0.05) in case of intra row spacing as and non significant in main effects of inter row spacing and interaction effects of two factors (Table 7).

Table 7. Effect of different plant configuration and row spacing on tuber yield of potato at Dadeldhura, Nepal

Inter row spacing(cm)	Tuber yield (kg)			
	Total yield per plant	Total yield per m^2	Marketable tuber yield per m^2	Unmarketable tuber yield per m^2
60 (1 RB)	0.67^{a}	3.87^{b}	3.48^{b}	0.20
45 (2 RB)	0.50^{b}	3.92^{b}	3.86^{b}	0.23
30 (3RB)	0.45^{b}	5.41^{a}	5.15^{a}	0.25
SE(±)	0.030	0.34	0.35	0.031
$LSD_{0.05}$	0.0924	1.02	1.06	ns
F-test	***	**	*	ns
Intra row spacing (cm)				
20	0.47^{b}	5.56^{a}	5.24^{a}	0.31^{a}
30	0.54^{ab}	4.18^{b}	3.95^{b}	0.22^{ab}
40	0.61^{a}	3.45^{b}	3.31^{b}	0.16^{b}
SE(±)	0.030	0.34	0.35	0.031
$LSD_{0.05}$	0.0924	1.02	1.06	0.0948
F-test	*	**	**	*
CV (%)	17	23.2	25.4	38

*Means followed by the same letter within a column are not significantly different (P > 0.05) from each other, LSD= Least significant difference, CV= Coefficient of variation, ns= non significant, SE (±) = standard error of mean. *, **, *** represent significant at 5%, 1% and 0.1% level of significance respectively.*

The highest yield of unmarketable tubers per m^2 (0.31 kg) was found in 20 cm which was at par with 30 cm and followed by 40 cm intra row spacing. The findings showed that in closer

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spacing, there is higher unmarketable tuber yield in an unit area because of production of higher unmarketable tuber number in closer spacing comparative to the wider spacing.

Harvest Index

The analysis of variance revealed that haulm fresh and dry weight per m^2 was found to be statistically non significant (P>0.05) in case of both main and interaction effects of inter and intra row spacing (Table 8). In case of harvest index, it was found statistically significant (P<0.01) in the main effect of inter row spacing whereas statistically significant at P<0.05 in the main effect of intra row spacing but not significant in the interaction effect of both factors. The highest harvest index (0.72) was found in 30 cm which was at par with 45 cm and followed by 0.68 intra spacing. Similarly, in case of intra row spacing, highest intra row spacing (0.72) was found in
20 cm which was at par with 30 cm and followed by 40 cm intra row spacing. The findings that closed spaced potato has higher harvest index than wider spaced potato plants. It is because the economic yield or total weight of potato is found higher in closed spaced plants in unit area due to large number of tubers from densely populated plants in closed spacing comparative to wider spacing.

Table 8. Effect of different plant configuration and row spacing on weight of haulm and harvest index of potato at Dadeldhura, Nepal

Inter row spacing(cm)	Haulm Fresh weight in kg per m^2	Haulm dry weight in kg per m^2	Harvest index(HI)
60 (1 RB)	1.48	0.43	0.68^b
45 (2 RB)	1.30	0.38	0.71^a
30 (3RB)	1.69	0.49	0.72^a
SE(±)	0.18	0.053	0.00844
$LSD_{0.05}$	ns	ns	0.0253
F-test	ns	ns	**
Intra row spacing (cm)			
20	1.78	0.52	0.72^a
30	1.44	0.42	0.70^{ab}
40	1.25	0.36	0.68^b
SE(±)	0.18	0.053	0.00844
$LSD_{0.05}$	ns	ns	0.0253
F-test	ns	ns	*
CV (%)	37.1	37.1	3.59

*Means followed by the same letter within a column are not significantly different (P > 0.05) from each other, LSD= Least significant difference, CV= Coefficient of variation, ns= non significant, SE (±) = standard error of mean. *, **, *** represent significant at 5%, 1% and 0.1% level of significance respectively.*

Physical parameter; Grading of potatoes
Small sized potato (1-2.5 cm)

The analysis of variance showed that there was significant difference (P<0.05) in the number of small sized potato per m^2 in main effect of inter row spacing and significant at P<0.01 in the main effect of intra row spacing and there was no any significant interaction effect between the two factors (Table 9). The highest number of small sized potatoes per m^2 (60.25) was found in 30cm which was at par with 45 cm and followed by 60 cm inter row spacing whereas in the case of intra row spacing, the highest number of small sized potatoes per m^2 (66.06) was found in 20cm which was followed by 30 cm and 40 cm intra row spacing

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respectively.
Similarly, weight of small sized seed per m^2 was found significant (P<0.01) in the main effect of inter row spacing and significant at P<0.001 in the main effect of intra row spacing. The highest weight of small sized seed (1.45 kg/m^2) was found in 30 cm which was followed by 45 and 60 cm inter row space respectively. In case of intra row spacing, highest weight of small sized potatoes (1.59 kg/m^2) was found in 20 cm which was followed by 30 cm and 40 cm intra row space respectively.

Table 9. Effect of different plant configuration and row spacing on grading of potato at Dadeldhura, Nepal

Inter row spacing(cm)	Small sized seed(1-2.5cm)		Medium sized seed(2.5-3.5cm)		Large sized seed(>3.5cm)	
	No per m^2	Kg per m^2	No per m^2	Kg per m^2	No per m^2	Kg per m^2
60 (1 RB)	31.62(1.50)^b	0.68(0.22)^b	51.17^c	1.91^b	8.67	0.89
45 (2 RB)	45.70(1.66)^{ab}	0.99(0.30)^b	70.39^b	2.48^b	5.34	0.5
30 (3RB)	60.256(1.78)^a	1.45(0.39)^a	97.25^a	3.25^a	5.18	0.48
SE(±)	0.0586	0.029	5.1	0.22	1.09	0.2
$LSD_{0.05}$	0.176	0.0885	15.3	0.674	ns	ns
F-test	*	**	***	***	ns	ns
Intra row spacing (cm)						
20	66.06(1.82)^a	1.59(0.41)^a	94.36^a	3.17^a	6.23	0.65
30	42.65(1.63)^b	0.90(0.28)^b	65.01^b	2.43^b	6.83	0.62
40	30.90(1.49)^b	0.67(0.22)^b	59.44^b	2.04^b	6.14	0.59
SE(±)	0.0586	0.029	5.1	0.22	1.09	0.24
$LSD_{0.05}$	0.176	0.0885	15.3	0.674	ns	ns
F-test	**	**	***	**	ns	ns
CV (%)	10.6	28.7	21	26.4	ns	ns

*Means followed by the same letter within a column are not significantly different (P > 0.05) from each other, LSD= Least significant difference, CV= Coefficient of variation, ns= non significant, SE (±) = standard error of mean. The figures inside the parenthesis are the log transformed values. *, **, *** represent significant at 5%,1% and 0.1% level of significance respectively.*

Medium sized potato (2.5-3.5 cm)

The analysis of variance showed that there was significant difference (P<0.001) in the number of medium sized potato per m^2 in main effect both of intra row spacing (Table 9). The highest number of medium sized potatoes per m^2 (97.25) was found in 30cm which was followed by 45 cm and 60 cm inter row spacing whereas in the case of intra row spacing, the highest number of medium sized potatoes per m^2 (94.36) was found in 20cm which was followed by 30 cm and 40 cm intra row spacing respectively. There was significant interaction (P<0.05) between the two factors in the number of medium sized potato per m^2. In case of interaction, the highest number of medium sized potatoes was found in 30×20 spacing which was at par with 45×20 and followed by 30×30,30×40,60×30,60×20,45×40,45×30 and lowest in 60×40 spacing (Fig 4)
Similarly, weight of medium sized seed per m^2 was found significant (P<0.001) in the both main effects of inter row spacing and intra row spacing but not significant in the interaction effect of the two factors (Table 12). The highest weight of medium sized seed (97.25 kg/m^2) was found in 30 cm which was followed by 45 and 60 cm inter row space respectively. In case of intra row spacing, highest weight of small sized potatoes (94.36 kg/m^2) was found in 20 cm which was followed by 30 cm and 40 cm intra row space respectively.

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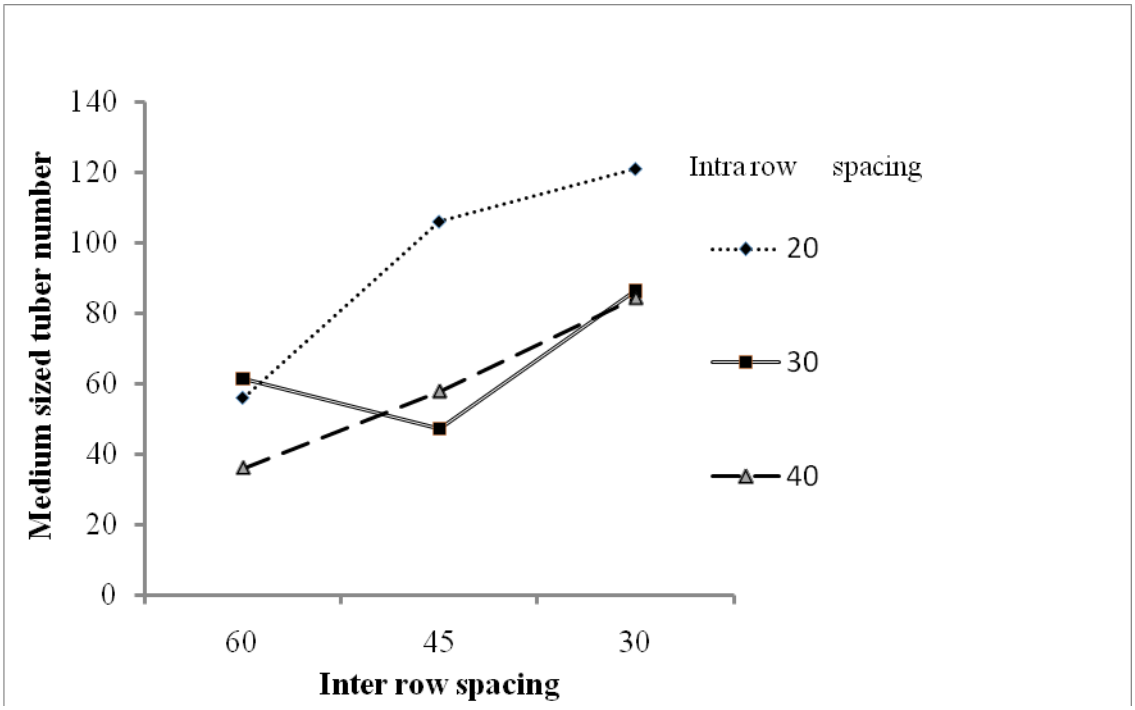

Fig 4: Relationship between Inter-Intra row spacing and Medium Sized tuber number

Large sized potato (>3.5 cm)

The analysis of variance showed that there was no any significant difference ($P<0.05$) in both number and yield of large sized potato per m^2 in both main and interaction effect of both factors (Table 9). About 6-8 number and 0.4-.0.9 kg per m^2 of large sized tuber were found in all treatments. The non significant result may be due to treatment design, soil conditions, experimental setup which differs from the previous similar experiment done by other researchers.

Correlation analysis of growth and yield parameters

Correlation analysis among growth and yield parameters showed that number of leaves($r=0.98$), leaf area index ($r=0.96$) was positively correlated at $P<0.001$ with average tuber weight (Fig 5). Similarly, germination days, flowering days, maturity days, average number of tillers, number and weight of marketable tubers, fresh weight of haulm and harvest index also positively correlated with average weight of tubers. Average weight of tubers negatively correlated with plant height, number of tillers and unmarketable tuber number. It means increase in plant height, tiller number and unmarketable tuber decrease the total weight of tubers but increase linearly with number of leaves, leaf area index and marketable tuber number and its weight.

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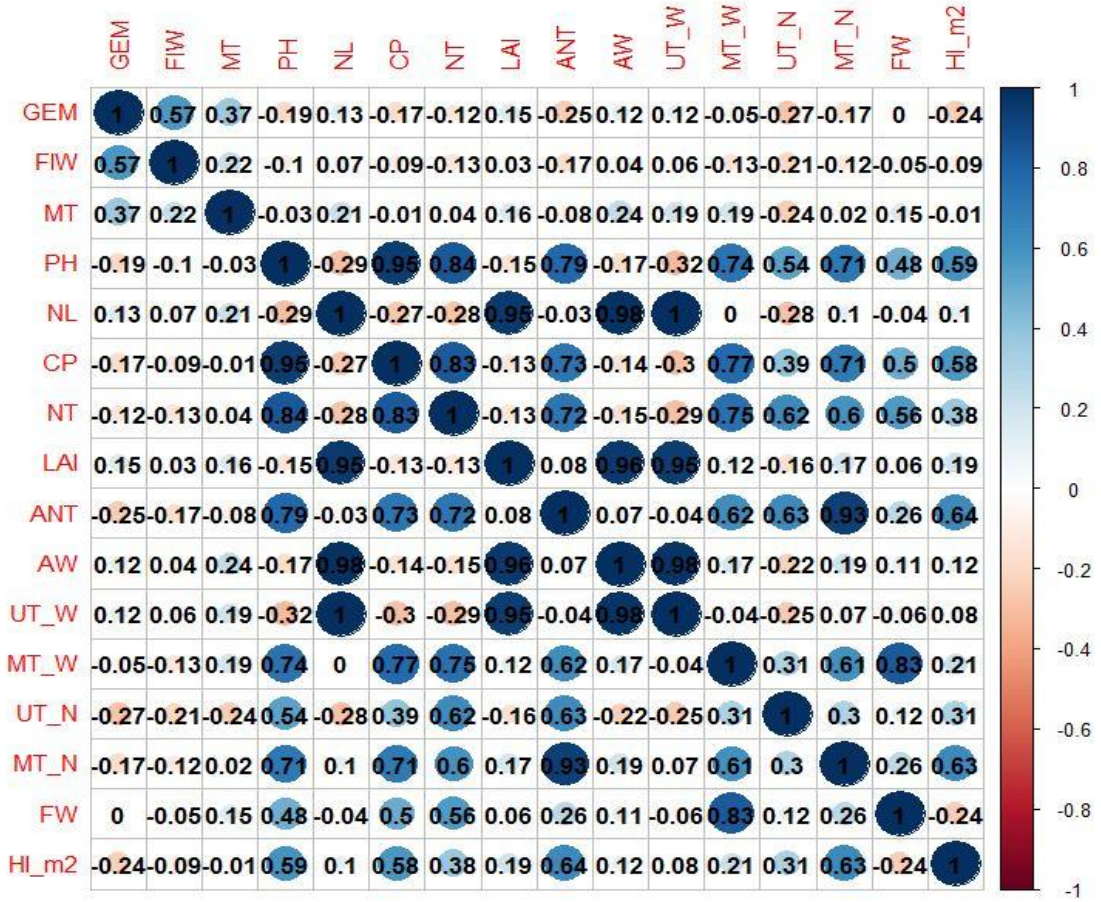

Fig 5: Correlogram showing correlation analysis of yield and growth parameters.
Note: The scale in the right side and values inside the columns indicates Pearson Correlation value (>0= positively correlated, <0 = negatively correlated). Circle size and intensity (Green) in the graph increases along with level of Positive correlation whereas intensity of red color and circle size increases along with the level of negative correlation. R critical value; $R_{0.05}$=0.328, $R_{0.01}$=0.445 and $R_{0.001}$= 0.568
GEM= Days to germination, FLW= Days to flowering, MT= Days to maturity, PH= Plant height, NL = Number of leaves, CP= Canopy diameter, NT= Number of tillers, LA= Leaf Area, LAI= Leaf Area Index, ANT= Average number of tubers per, AW= Average weight of tuber , UT_W= Average weight of unmarketable tubers, MT_W= Average weight of marketable tubers, UT_N= Number of unmarketable tubers, MT_N= Number of marketable tubers, FW= Fresh weight of tubers, HI_m2= Harvest index

DISCUSSION

On 50 % germination, flowering and maturity that there was no significant difference effects of inter and intra row spacing on potato which was also concluded by Arega *et.al* (2018). This might be the fact that these traits related to germination, flowering and maturity are controlled by genetic factors rather than environmental factors like plant spacing. The findings showed that change in inter and intra row spacing does not change the number of tillers. Similarly, Endale and Gebremedhin (2008) reported that main stem numbers depend

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on seed bed conditions, planting method and seed tuber characteristics such as number of eyes or sprouts, size, physiological age and variety. In growth parameters like plant height, leaf area, number of leaves, canopy diameter was found highest in higher row spacing due to increase in vegetative growth as a result of less competition in wider spaced plants comparative to narrow spaced plants which was also reported by Bikila *et al*. (2014), Gulloglu and Argioglu (2009), LawOgbomo and Egharevba, (2009) Tesfaye *et al.* (2012) Zamil *et al*. (2010) Zebarth *et al*., (2006)

Yield parameters like total number and yield of tubers m^{-2}, number and weight of marketable tubers m^{-2},harvest index, number and yield of small sized tubers m^{-2} , and number and yield of of medium sized tubers m^{-2} was found higher in lower inter and intra row spacing because of large number of medium and small sized tubers having higher proportion in total yield and number of tubers produced in narrow spaced plants compared to closed spaced plants which was also reported by Gulluoglu and Arioglu (2009), Zamil *et al*., (2010) Jamaati *et al*. (2010), Tahmorespour *et al*. (2013), Ayupov *et al.* (2014), Zabihi *et al*. (2010), Masarirambi *et al*. (2012), Tesfaye *et al*. (2012), Harnet et al. (2014), Bikila et al. (2014). Increased in yield and yield attributes in many rows per bed system compared to conventional system of planting configuration was in accordance with Tarkalson *et al*.(2011).

CONCLUSION

The study concluded that 30 cm inter row with 3 rows per bed and 20 cm intra row spacing resulted in higher weight and number of total and and marketable tubers. The higher marketable tuber number was found in the treatment combinations like 30×20 cm, 45×20 and 30×30 spacing. The highest harvest index was also found in 30 cm inter row with 3 rows per bed and 20 cm intra row spacing. In case of grading, to get small and medium sized potatoes which can be used for seed purpose were also found higher in 30 ×20 spacing. So this research recommends to use 30 or 45 intra row with triple rows per bed and 20 inter row spacing as possible which can provide greater total and marketable yield.

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