Research Article

Efficacy of Sowing Orientation and Maize Intercropping on Potato Crop at Higher Elevations

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Abstract | Sowing orientation and intercropping are environment friendly methods to manage the weed menace in agricultural crops. In this connection, a field experimentation was conducted at Agriculture Research Station, located at Seenlasht area of Chitral, Pakistan during growing season of Potato crop in 2020 to assess the effect of sowing orientation of potato crop (Factor A) and of maize crop when intercropped with potato crop (Factor B) on the yield of potato crop and the associated weeds. In this connection, a 2-factorial experiment was designed, with three replications of the experiment. There were two sowing orientations i.e. North-South and East-West sowing of the crop rows. The Factor B comprised of five different intercropping treatments (viz. sole potato, one row each of potato and maize, one row of potato and two rows of maize, two rows of potato and one row of maize, and two rows each of potato and maize. Data collection was carried out for weed density (m^{-2}), fresh weed biomass (kg ha^{-1}), potato plant height (cm), no. of leaves plant^{-1}, tuber yield (t ha^{-1}), maize yield (t ha^{-1}) and LER. Ultimately, the results of the experiment showed a statistically significant influence of the sowing orientation, intercropping and the interaction effect on the investigated parameters of weeds and potato crop both. The sowing of potato crop in E-W orientation disclosed statistically significant escalation in the weeds density (115.81 m^{-2}), weeds biomasses (1154 kg ha^{-1}), and potato plant height (57.45 cm); whereas N-S orientation resulted in increased number of leaves plant^{-1} (24.28), tuber weight plant^{-1} (356.74 g), tuber yield (21.0 t) and maize yield (4.25 t ha^{-1}). The weed biomass was reduced by sowing crop in the N-S orientation and increasing the crop population. For the intercropping effect, highest weeds density of 161.98 m^{-2} and weeds biomass of 1683 kg ha^{-1} was noted in the sole potato crop as compared to the intercropping treatments of the experiment. The plant height of potato crop was higher in the intercropping treatments. Similarly, maximum no. of leaves, and tubers yield were obtained in sole sowing of potato crop. Intercropping potato and maize crops in a ratio of 1:2 resulted in lowest weeds density, fresh weeds biomass, no. of leaves plant^{-1}, and tubers yield. On the other hand, maximum maize yield was recorded in sole maize crop as compared to intercropped plots. In conclusion, sowing of potato crop in N-S, along with intercropping of maize proved to be a best eco-friendly method for the weed control strategy and yield improvement of potato crop at higher elevations.

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Introduction

Potato *(Solanum tuberosum)* is one of the major vegetable crops of Pakistan and is grown worldwide. Most of the global potato production is no more accomplished by the developed countries; instead it has shifted to the Asian countries (Scott and Suarez, 2013; Scott and Pandey, 2021; Hu *et al*., 2025). Weed competition affects the growth of potato crop that rob away a significant amount of major nutrients tat trigger substantial reduction in potato yields. In addition to the yield reduction, weeds also hamper the mechanical operations in the fields for harvesting the tubers (Ganie *et al*., 2023). In light of Jaiswal and Lal (1996) report, weed competition decreases the tuber yield up to 42%, while weed management strategies may increase the tuber yields up to 18-82%.

Due to the higher nutritive value and also the energy production, potato crop does have a unique importance in Pakistan, where rapid human population's growth has increased the gap between the production and consumption of potato crop. Pakistan is blessed with broad edaphic and ecological sources that are required for ideal potato production. During 2019-20, at national level, the area under cultivation of potato was 0.1886 million ha, along with a total production of 4.61 million t, at a mean yield of 23.6 t ha^{-1} in Pakistan (MINFA, 2021). At provincial level, the figures during the same cropping year were 835 ha, 10615 t, and 12.7 t ha^{-1}, respectively. Generally, more than Rs. 3 billion is lost annually due to the weed competition, while more than 38% yield losses may occur just in potato crop (Hassan and Marwat, 2001). Ganie *et al*. (2023) has calculated the yield losses of 12 to 60 % in potato crop due to weed competition. Potato yield losses of 24% due to various pests have been reported in which the losses due to weeds were 5% (Anonymous, 2002). However, Khan *et al*. (2009) were of the view that weeds can result in higher yield losses than any of the rest of the crop pests.

In light of the world's preference towards organic farming and avoiding the chemical control of weeds, there is definitely a significant need of utilizing environment friendly weed control methods to tackle the weed menace in potato crop along with ensuring the environment and health safety. Sowing orientation and intercropping both are the most important environment friendly weed management tools to influence the crop weed interactions in potato crop. Sowing orientation i.e. sowing potato crop in North-South or East-West orientations can be beneficial in many ways. There could be better light interception and improved photosynthesis due to which a well-developed canopy may shade the soil surface which may ultimately reduce the weed germination and growth. The key purpose of utilizing a multiple-cropping-system is that it integrates two or more crops to more efficiently use the same space and labor (Baldy and Stigter, 1997). Moreover, the intercrops should belong to the leguminosae family to restore the soil fertility in diverse cropping. In addition, the rooting depths of the two crops should be different and the two crops should also have different requirements for nutrients.

Thus, keeping in view the important role of weed control in potato crop, the instant field trial was conducted to assess two different eco-friendly weed control strategies for the purpose of increasing the potato yield and decreasing the weeds infestation.

Materials and Methods

Site of the experiment and agronomic practices

The field trial was conducted at the Agriculture Research Station (ARS), Seenlasht Chitral during the potato cropping season, 2019-20. The treatments consisted of two factors i.e. sowing orientations and intercropping. There were two levels of sowing orientation (east west sowing and north south sowing) whereas there were six levels of intercropping treatments viz. sole potato, sole maize, and four other different planting ratios of potato and maize viz., 1:1, 1:2, 2:1, and 2:2. The treatments were laid out in a two factorial design, keeping three replicates.

The potato variety, Karoda was sown as the main crop and maize variety, Azam was sown as the intercrop. Moreover, a fertilizer dose of 150:100:125 kg ha^{-1} was applied to potato crop and of 110:90:75 kg ha^{-1} to maize crop. Disease free and well developed potato tubers were sown in ridges; while maize seeds were sown in between the rows of potato tubers that were spaced at 60 cm row-row and 25 cm plant-plant distances. The experiment was irrigated as per requirement of the crops. In intercropping situations, maize plants received the practices similar to the potato crop (main crop). Ten randomly selected plants were tagged for data observations, as the border rows from each unit plot were not tagged, and finally the averages were computed. For maize crop, only the maize yield data was recorded. For weeds related parameters, the data recording was done on weeds density (m^{-2}) and biomasses (kg ha^{-1}); while for potato crop, the data were taken on potato plant height (cm), no. of leaves $plant^{-1}$, and tuber yield (kg ha^{-1}). For maize crop, the data were recorded only on the maize yield. The LER values for each intercropping treatment were also calculated.

A large quadrate having a size of 1m × 1m was randomly thrown three times in each of the treatments. After that, averages were taken for the number of weeds m^{-2}. For fresh weed biomass data, all the fresh weeds in the central 3-rows of each unit plot were ripped up, and immediately weighed with the help of a digital electrical balance. The values obtained from the plots were converted to kg ha^{-1} in both of the experiments. The plant height data was taken at the physiological maturity of potato crop. Thus, 10 representative potato plants in each of the plots were selected randomly. Their required heights were measured from the ground surface to the plants extreme tips, using a scaled tape. Afterwards, the required means were computed separately for each of the treatments. Data on no. of leaves $plant^{-1}$ was measured by counting the leaves of five randomly selected potato plants from each treatment. Later on, the means of all the five plant samples were determined as the no. of leaves $plant^{-1}$. The following formula was used to record the data for potato tubers yield (tha^{-1}):

$$Tubers\ yield\ (tha^{-1}) = \frac{\text{Yield in subplot (kg) x 10000 m}^2}{\text{Area of subplot (m}^2\text{) x 1000}}$$

For land equivalent ratio, potato partial LER (LERpotato) and maize (intercrop) partial LER (LER_{Maize}) were calculated, using the following formula generated by Willey (1990).

$$LER(PM) = LER-P + LER-M = YIP/YSP + YIM/YSM$$

Where, P stands for potato, M for maize, YIP = yield of inter-cropped potato (main crop), YIM = yield of inter-cropped maize (inter-crop), YSP = yield of sole potato (main crop), YSM = yield of sole maize (inter-crop).

All the data collected on various parameters of weeds and crops were statistically analyzed, using the procedure required for a two factorial RCB design. The two factors were sowing orientation and intercropping. After obtaining significant F-test results for a parameter, the least significant difference (LSD) test was conducted to compare the different treatment means, at level of probability (α) of 5% (Steel and Torrie, 1980). The main effects were presented in tables while the interaction effects were presented graphically.

Results and Discussion

Weed density (m^{-2})

According to the data given in table, the sowing orientation, inter-cropping treatments, and their interactions had a significant effect on the density of weeds (Table 1). The plots of potato where potato crop was sown in north-south orientation showed significantly lower weed density of 98.85 weeds m^{-2} in comparison with the potato sown in the E-W orientations (115.81 weeds m^{-2}). Regarding the intercropping effect, the weeds density was lowest (81.82 m^{-2}) in the intercropping of potato (1 row) and maize (2 rows) (1:2); while highest in sole potato plots (161.98 m^{-2}). The north south orientation allowed for more uniform sunlight penetration during the day, as a result of the higher row-row distances than the plant-plant distances, helping potato plants develop better canopy coverage. A well-developed canopy shades the soil surface, reducing weed germination. Proper orientation ensures maximum leaf area exposure to sunlight, increasing photosynthesis efficiency. This typically improves tuber bulking and overall yield. A reduced number of weeds per unit area were reported in the north south row orientation (Karanja *et al*., 2014). On the other hand, the highest weed biomass was found in sole potato plots because of availability of sufficient space for weeds germination and growth. Our results are in harmony with that of Jasrotia *et al*. (2023) who were of the view that intercropping potentially suppresses weeds and it helps in capturing a higher share of the available resources as compared to the mono-cropping. The interaction effect was also significant. Maximum weed density (169.64 m^{-2}) was found in sole potato plants, that were sown in east-west orientations, while minimum weed density (70.00 m^{-2}) was noted in plots where potato was grown in north south orientations, with the intercropping of one row of potato (main crop) with two rows of maize (the intercrop).

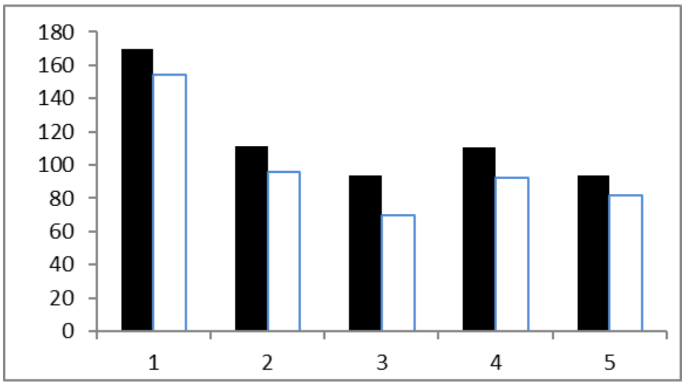

Figure 1: *Influence of the interaction of sowing orientation (SO) and inter-cropping (IC) on the weeds density m^{-2} in potato crop in Chitral, Pakistan. Black bar (East west orientation), White bar (North south orientation), 1 (sole potato), 2 (1 row each of potato and maize), 3 (1 row of potato and 2 rows of maize), 4 (2 rows of potato and 1 row of maize), 5 (2 rows each of potato and maize).*

Weed biomass (kg ha^{-1})

According to the data analysis, the fresh weed biomass (kg ha^{-1}) was significantly ($p<0.05$) affected by sowing orientation, intercropping and their interaction (Table 1). Significantly lesser weed biomass (1082 kg ha^{-1}) was found in potato plots having row orientation in the N-S orientation, compared to the sowing in east-west orientation where the weed biomass was 1154 kg ha^{-1}. The weed biomass was highest (1683 kg ha^{-1}) in treatments of sole potato, followed by intercropping of potato and maize with one row each alternatively (1134 kg ha^{-1}). However, lowest fresh weeds biomass was observed in intercropping of one row sole potato and two rows of maize (721 kg ha^{-1}). Here, the sowing of potato crop plants in the N-S orientation might have received effective solar radiations, compared to that in E-W sowing orientation. This could be due to the distance between rows of potato plants is greater than the distance between plant to plant, which enhanced the competitiveness of the crop plants that indirectly resulted in reduced weeds biomass in north south orientation plots (Monem *et al*., 2012). Higher yields for sorghum crop were reported by Karanja *et al*. (2014), due to the declined fresh weeds biomass in the N-S orientation of crop rows. All the four inter-cropping treatments significantly reduced the weeds biomass that can be attributed to the better utilization of the available resources and higher interspecific competition among crops and weed plants (Hauggaard-Nielson *et al*., 2003; Khan *et al*., 2009). For the interaction effect, highest weed biomass (1751 kg ha^{-1}) was observed in sole potato plots sown in east-west orientation, while lowest weed biomass (701 kg ha^{-1}) was noted in plots with the two crops grown in the N-S orientations with intercropping in the ratio of one row of potato to two row of maize.

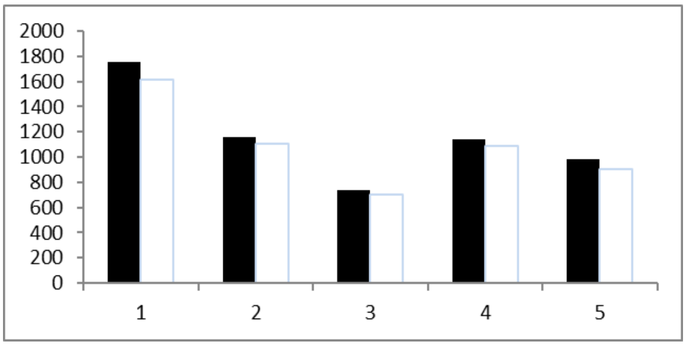

Figure 2: *influence of the interaction of sowing orientation (SO) and inter-cropping (IC) on the fresh weeds biomasses (kg ha^{-1}) in potato crop in Chitral, Pakistan. Black bar (East west orientation), White bar (North south orientation), 1 (sole potato), 2 (1 row each of potato and maize), 3 (1 row of potato and 2 rows of maize), 4 (2 rows of potato and 1 row of maize), 5 (2 rows each of potato and maize).*

Plant height of potato (cm)

After the data analysis, a statistically significant influence of the sowing orientation, intercropping and their interaction was found on the plant height of potato (Table 1). Comparatively, potato plants were higher (54.84 cm) in plots where potato plants were sown in the N-S orientations, compared to plots where potato crop was sown in the E-W orientations (57.03 cm). Significant differences in potato plant heights were observed between mono-cropping and intercropping, where average plant height was bigger in the intercropping (63.00 cm) and smaller in the mono-cropping treatment (46.78 cm). This difference might be because of higher light-capturing by the taller plants in the intercropping treatments. Usually, the height of plants increases with rise in the natural competition for the available but limited natural resources, amongst the weeds and crop plants. So, this happens mostly in situations of competition for sunlight (Mochiah *et al*., 2012). Technically, the rise in plant height does not inevitably correspond to the surge in crop yield, as yield is a reproductive character; while plant height is a vegetative character on the other side (Mochiah *et al*., 2012; Bhattarai *et al*., 2024). Plant height was recorded highest (63.25 cm) in plants sown in east-west orientation with intercropping, while lowest height (43.91 cm) was noted in north south orientation in sole potato.

Table 1: *Influence of sowing orientation and intercropping of potato and maize on weeds density, fresh weeds biomasses, potato plants heights and no. of leaves plant^{-1} in Chitral, Pakistan.*

Treatments	Weeds density (m^{-2})	Weeds biomass (kg ha^{-1})	Potato plant height (cm)	No. of leaves plant^{-1} of potato
Sowing orientation (SO)				
East-West sowing	115.81 a	1154 a	57.03 a	23.81
North south sowing	98.85 b	1082 b	54.84 b	24.28
Significance level	*	*	*	NS
Intercropping (IC)				
Sole Potato	161.98 a	1683 a	46.78 c	28.80 a
Potato 1 row: Maize 1 row (1:1)	103.58 b	1134 b	54.76 b	25.89 b
Potato 1 row: Maize two rows (1:2)	81.82 c	721 d	60.08 a	19.26 e
Potato 2 rows: Maize 1 row (2:1)	101.61 b	1112 b	55.05 b	24.80 c
Potato 2 rows: Maize 2 rows (2:2)	87.66 c	943 c	63.00 a	21.48 d
LSD(0.05)	11.60	109	4.30	0.78
Interactions				
SO x IC	16.34	154.30	6.08	NS

*The mean values that are followed by different alphabetical letters are significantly different at α = 0.05. (LSD values or * = Significant, NS = Non-significant).*

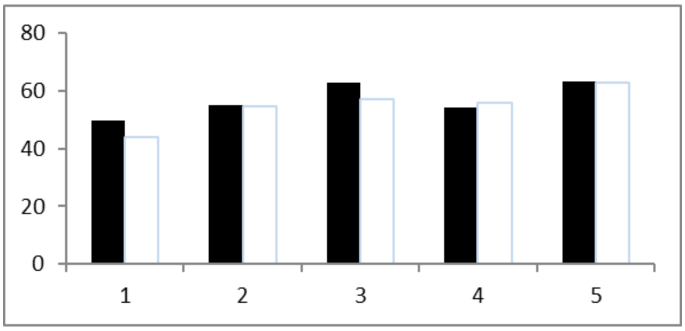

Figure 2: *Influence of the interaction of sowing orientation (SO) and inter-cropping (IC) on the plant height (cm) of potato crop in Chitral, Pakistan. Black bar (East west orientation), White bar (North south orientation), 1 (sole potato), 2 (1 row each of potato and maize), 3 (1 row of potato and 2 rows of maize), 4 (2 rows of potato and 1 row of maize), 5 (2 rows each of potato and maize).*

Number of leaves plant^{-1}

It is obvious from the data analysis that there was a significant effect of intercropping on the no. of leaves plant^{-1} of potato crop, while the effect of sowing orientation and interaction of sowing orientation with intercropping was non-significant on no. of leaves plant^{-1} (Table 1). Plants grown in east-west orientation produced less number of leaves plant^{-1} (8.44), compared to the sowing of the potato crop plants in the N-S orientation (9.47). Regarding intercropping maximum number leaves plant^{-1} (28.80) were noted in sole potato treatments while less no. of leaves plant^{-1} of potato (19.26) in the intercropped plots.

Tuber yield (t ha^{-1})

It is clear from the analyses of data, that the sowing orientation, intercropping significantly influenced the yield of potato tubers (tha^{-1}); however the interaction effect was non-significant, as given in Table 2. As a result, the tubers yield was significantly higher ($p<0.05$) in north-south row sowing (20.90 tha^{-1}) than that in the row sowing in the EW orientation (20.12 t ha^{-1}). As regards the intercropping, highest tuber yield (25.48 t ha^{-1}) was noted in sole potato plots, whereas lowest (15.67 tha^{-1}) was noted in intercropping plots with two rows of maize (intercrop) with one row of potato (main crop). Light being important factor for photosynthesis plays an important role in growth and yield of plant. As in north south row orientation the crop plants receive more solar radiation than the east west row orientation which is apparently because of the higher distance between rows than the spacing between the crop plants so there will be more photosynthesis and more yield will be there. The canopy coverage of the individual potato crop plants overlaps with the adjacent other plants in the vicinity, which consequently renders the conditions that are favorable for photosynthesis in plots where the sowing orientation was in the north south orientation. Higher yields for sorghum crop were reported by Karanja *et al.* (2014) in the north south row orientation but lower yields for cowpea crop, compared to row orientation in the E-W orientations. The highest tuber yield found in potato crop when planted as single main crop might be due to highest tuber diameters and weights. It has been reported that the gross productivity of the potato crops decreased when it is inter-cropped with maize crop, as compared to the sole potato crop (Ebwongu *et al*., 2001; Sharaiha and Hadid, 2008).

Table 2: *Influence of the sowing orientation and inter-cropping on potato tubers yield (t ha^{-1}) and maize yield (t ha^{-1}) in Chitral, Pakistan.*

Treatments	Potato tubers yield (t ha^{-1})	Maize crop yield (t ha^{-1})
Sowing orientation (SO)		
East-West sowing	20.12 b	3.96
North south sowing	20.99 a	4.25
Significance level	*	NS
Intercropping (IC)		
Sole Potato	25.48 a	5.35 a
One row of potato : one row of maize (1:1)	19.89 c	3.63 d
One row of potato : two rows of maize (1:2)	15.67 d	4.74 b
Two rows of potato : one row of maize (2:1)	22.37 b	2.75 e
Two rows of potato : two rows of maize (2:1)	19.38 c	4.07 c
LSD (0.05)	0.57	0.14
Interactions		
SO x IC	NS	NS

*The mean values that are followed by different alphabetical letters are significantly different at α = 0.05; (LSD values or * = Significant, NS = Non-significant).*

Maize yield (t ha^{-1})

Maize yield was significantly ($p<0.05$) affected by the intercropping treatments while the effect of sowing orientation and interactions was non-significant (Table 2). Regarding the sowing orientation, higher maize yield (4.25 t ha^{-1}) was found in treatments where crops were sown in the N-S orientations, while lower maize yields (3.96 t ha^{-1}) were noted in plots where sowing was done in the east-west orientations. The maize yield was highest (5.35 t ha^{-1}) in sole maize plots as compared to the plots intercropped with potato (2.75 t ha^{-1}). Similar results were also recorded by Bantie (2015) who recorded a decline in average productivity of maize (5-60 %) under inter-cropping system, as compared to sole cropping of maize (4.3 t ha^{-1}).

Land-equivalent-ratio (LER)

In fact, the LER is a vital factor in inter-cropping systems, because it investigates the net benefit of simultaneously growing two or more agricultural crops on a specific piece of land, compared to growing them separately. Generally, if LER reaches the value of one, it will indicate a positive effect of intercropping method. As far as the results are concerned, the LER was better in most of the studied inter-cropping treatments. Therefore, the yields achieved from the investigated crops both in sole situation as well as inter-cropping situations (with maize as intercrop) are mentioned in Table 3. The biggest LER of 1.52 was achieved in intercropping treatment of 2 rows each of potato and maize, followed by 1.51 in intercropping of maize 2 rows with potato 1 row (1:2). The smallest LER (1.39) was calculated in the intercropping treatment of potato two rows x maize one row (i.e. 2:1). It can thus be deduced that intercropping system does have the optimum capacity to generate substantially larger net incomes against the mono-cropping system.

Table 3: *The influence of potato and maize grown sole or as intercrops (IC) on their respective land equivalent ratios (LERs) at Chitral, Pakistan.*

Treatments	Partial LER		Total LER
	Po	Mz	
One row of potato: one row of maize (1:1)	0.78	0.68	1.46
One row of potato: two rows of maize (1:2)	0.62	0.89	1.51
Two rows of potato: one row of maize (2:1)	0.88	0.51	1.39
Two rows of potato: two rows of maize (2:1)	0.76	0.76	1.52

Conclusion

The following are the conclusions generated in light of the results. Sowing of the potato plants in row orientation of north south gave better results than sowing in the east west orientation in the agro-ecological conditions of Chitral, regarding weed management and potato crop yield. Inter-cropping of maize is a best option for avoiding the weed infestation and more production from the same piece of land. Crop row orientation has no negative effect on potato crop in the farming system. Therefore, it should be adopted on large scale because of being cost effective and eco-friendly. Along with the N-S and E-W row orientations, the diagonal orientations of the two may also be tested. The same treatments can also be investigated for their effect on all other varieties of the potato crop and also in other ecological conditions as well.

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Novelty Statement

The combination of sowing orientation and maize intercropping to assess their effect on the growing weeds and at the same time on the yield of potato crop particularly in the agro ecological conditions of Chitral (a higher elevation area) is a novel study.

Author's Contribution

As a sole author, all the activities of this research have solely been planned, supervised and conducted by the author with the help of a couple of workers. All the requirements for publication of the article from write-up to galley proof have been fulfilled by the author alone.

Generative AI and AI-assisted technology statement
Generative AI tools were not used to generate, analyze, or interpret the core content of this manuscript. Any AI-assisted technology used was limited to language editing and formatting support, without influencing the originality or intellectual contribution of the authors.

Conflict of interest
The authors have declared no conflict of interest.

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