Nutrients dynamics and uptake patterns in groundnut (*Arachis hypogaea* L.)- sweet corn (*Zea mays* var. *Saccarata*) intercropping systems

Abstract:A field experiment was conducted in the summer season during 2020-21 and 2021-22 on clayey soil at Regional Rice Research Station, NAU, Vyara (Gujarat), Indiato evaluate the nutrients dynamics and uptake patterns of groundnut-sweet corn intercropping systems. The experiment comprised of ten treatments which was laid out in randomized block design with three replications. The results showed that the productivity of these systems in terms of groundnut pod equivalent yield 3221 kg/ha was significantly higher with intercropping of groundnut + sweet corn (2:1) with paired row (30-60-30 cm) (T_{10}) followed by groundnut + sweet corn (3:1) in additive series (3073 kg/ha)(T_8). Maximum N and K balance was recorded in case of treatment T_{10} (+107.18 and +144.52 kg/ha, respectively) which was followed by groundnut + sweet corn (2:1) in replacement series (T_4) (+71.14and +108.78 kg/ha, respectively) and (3:1) in additive series (T_8) (+56.35and +107.44 kg/ha, respectively). Phosphorus balance was negative under all treatments of intercropping system.
Keywords: Available nutrient, Uptake and Nutrient balance

1. Introduction

India has a greater diversity of crops than any other country due to its varied climate, with the two most common cereal-based farming systems being rice-wheat (10.5 m ha) and rice-rice (5.9 m ha) (Kumar *et al*., 2023). In Gujarat,Tapi is primarily an agricultural district with paddy and sugarcane as the predominant crops and it has a net sown area (1.59 lakh ha) constitutes about 49% of the total geographical area (3.25 lakh ha) and the net irrigated area (0.67 lakh ha) forms 42% of the net sown area. (*Annon*., 2023-24). Continuous cultivation of rice for a longe period with low system productivity and often with poor crop management practices, results in loss of soil fertility due to emergence of multiple nutrient deficiency and deterioration of soil physical properties, and decline in factor productivity and crop yields in high productivity areas (Yadav and Chauhan, 1998). During cultivation of rice, soil undergoes drastic changes, *i.e*., aerobic to anaerobic environment, leading to several physical and electrochemical transformations. If this is the case, then perhaps there is an important role for crop diversification that includes upland crops, such as legumes, to induce sequestration of N.

Groundnut-sweet corn intercropping introduces a sustainable farming model in rice-based systems. By diversifying crop types, improving soil fertility, and optimizing water and nutrient use, this intercropping system reduces the environmental footprint of intensive rice farming. Groundnut, as a nitrogen-fixing legume, plays a critical role in replenishing soil nitrogen levels through its symbiotic relationship with rhizobia bacteria. Intercropping groundnut with sweet corn after rice harvesting helps restore soil fertility, reducing the need for synthetic fertilizers in subsequent cropping seasons. It also promotes the practice of minimal external input farming, supporting the long-term health of the agricultural ecosystem. Keeping this in view, the field study was conducted to assess the effect of groundnut-sweet corn intercropping on soil available N, P and K, nutrient uptake, nutrient balance and crop yield.

2. MATERIALS AND METHODS

2.1 Experimental site and soil type

The field experiment was laid out during summer season of the year 2020-21 and 2021-22 at the Regional Rice Research Station, Navsari Agricultural University, Vyara, Tapi district of Gujarat. The soil of the experimental area falls in the order Inceptisols comprising members of fine, montmorillonitic, isohyperthemic family of VerticUstrochrepts soil series.

2.2 Treatment details

There were ten intensified intercropping systems examined under randomized block design with three replications viz., sole groundnut (T_1); sole sweet corn (T_2); groundnut + sweet corn in 1:1 (T_3), 2:1 (T_4) and 3:1 (T_5) row ratio in replacement series; groundnut + sweet corn in 1:1 (T_6), 2:1 (T_7) and 3:1 (T_8) row ratio in additive series; mix sowing of groundnut 80% + sweet corn 20% (T_9) and groundnut + sweet corn (2:1) with paired row (30-60-30 cm) (T_{10}). During summer season both the crops were applied with the recommended dose of N, P_2O_5 and K_2O (Kg/ha). The source of nitrogen (N), phosphorus (P) and potassium (K) were urea, di-ammonium phosphate and muriate of potash.

2.3 Analysis of soil and plant samples

A composite soil sample was collected from 0-15 cm depth of the experimental field before commencement of the experiment for analysis.Following the crop harvest, soil samples were collected from each plot in order to study chemical changes brought about by intercropping cropping. The soil collected was then air dried, grounded and sieved through 2 mm sieve, labelled and stored for further analysis. The organic carbon was estimated by Walkley and Black method (Jackson,1974), available N by Alkaline potassium permanganate (Subbiah and Asija, 1956), available P by Olsen's (Chopra and Kanwar, 1976) and available K by flame photometric method (Jackson, 1974). Plant samples were also analysed for N content using modified Kjeldahl method (Jackson (1974)), P content using venedomolybdo phosphoric yellow colour method using spectrophotometer at 470 nm (Jackson, 1974) and K content was extracted by normal neutral ammonium acetate (1:40) and then determined by flame photometer method (Jackson, 1974). Analysis of soil sample collected before sowing for various physico-chemical properties have shown that soil was having clayey in texture (in both the years), medium in organic carbon (0.75 and 0.74%), neutral in reaction with pH (7.26 and 7.55) and EC (0.31 and 0.32 dS/m). The soil was medium in available nitrogen (296.3 and 307.1 kg/ha), available phosphorus (32.3 and 34.3 kg/ha) and available potash (289.3 and 293.4 kg/ha) in 2020-21 and 2021-22, respectively.

2.4 Statistical analysis

The data were subjected to statistical analysis by adopting analysis of variance. Wherever the F values found significant at 5% level of probability, the critical difference (CD) values were computed for making comparison among the treatment means as described by Panse and Sukhatme (1985).

3. RESULTS AND DISCUSSION

3.1 Groundnut pod equivalent yield

The data on groundnut pod equivalent yield are presented in Table 1. A close study of the data revealed that the mix/intercropping systems did exert their significant effect on groundnut pod equivalent yield in both the years as well as in pooled results.

Significantly the maximum groundnut pod equivalent yield (3108, 3333 and 3221 kg/ha) was produced under intercropping of groundnut + sweet corn with paired row (30-60-30 cm) (2:1) (T_{10}) during both the years and in pooled results, respectively, which stayed statistically at par with intercropping of groundnut + sweet corn (3:1) in additive series (T_8) during both the years and in pooled results. However, significantly the minimum groundnut pod equivalent yield (1161, 1262 and 1212 kg/ha) was produced under groundnut + sweet corn (1:1) in additive series (T_6) intercropping system during both the years and in pooled results, respectively.

Table1 Groundnut pod equivalent yield under different treatments.

Treatment	Groundnut pod equivalent yield (kg/ha)		
	2020-21	2021-22	Pooled
T_1	1755	1907	1831
T_2	1606	1603	1605
T_3	1787	1878	1832
T_4	2507	2834	2670
T_5	2084	2277	2181
T_6	1161	1262	1212
T_7	2195	2528	2362
T_8	2986	3159	3073
T_9	1791	2081	1936
T_{10}	3108	3333	3221
S.Em.±	87.53	95.20	64.66
C.D.	260	283	185
C.V. %	7.23	7.21	7.22

Year	
S.Em.±	24.38
C.D.	70
Y x T	
S.Em.±	91.44
C.D.	NS

3.2 Effect on available NPK status

A perusal of data indicated that different mix/intercropping systems exhibited their significant influence on post-harvest available nitrogen and potash in soil in pooled results (Table 2). Significantly the maximum value of post-harvest available nitrogen and potash in soil was noted under thesole groundnut and it followed the treatments T_3, T_4, T_5, T_7, T_8, T_9 and T_{10} (except treatmentT_3, T_7 and T_9 in available potash) in pooled results. In contrast, significantly the minimum value of post-harvest available nitrogen and potassium in soil were registered under the sole sweet corn in pooled results. This might be due to legumes help in improving the soil fertility *via* biological nitrogen fixation and reduce the competition for available N in soil due to the more competitive character of the cereal (Layek *et al*. 2014) and thus contribute to the complementary and efficient use of available N (Bedoussac and Justes, 2010).

Nutrients status in soil *viz.*, available phosphorus was not significantly influenced by different mix/intercropping systems (Table 2), but decreased under mix/intercropping systems over sole groundnut. This might be due to RDF and initial status of nutrients might have not supplied sufficient P under intercropping condition.

Table 2. Effect of different mix/intercropping systems on post-harvest soil available nitrogen, phosphorus and potash

Treatment	Available nitrogen (kg/ha)			Available phosphorus (kg/ha)			Available potash (kg/ha)		
	2020-21	**2021-22**	**Pooled**	**2020-21**	**2021-22**	**Pooled**	**2020-21**	**2021-22**	**Pooled**
T_1	290.91	294.03	292.47	40.65	38.99	39.82	348.84	344.84	346.84
T_2	241.37	243.40	242.38	30.59	31.26	30.93	244.75	238.03	241.39
T_3	270.99	274.20	272.60	36.86	35.81	36.34	280.94	273.93	277.44
T_4	284.06	286.90	285.48	37.23	38.17	37.70	317.07	326.83	321.95
T_5	285.45	288.60	287.02	37.85	38.09	37.97	345.07	333.03	339.05
T_6	265.08	270.67	267.87	36.50	37.87	37.19	281.75	285.27	283.51
T_7	278.99	282.20	280.60	34.61	36.70	35.66	290.10	301.43	295.77
T_8	282.24	289.00	285.62	34.47	33.54	34.00	338.18	339.83	339.01
T_9	276.81	279.73	278.27	31.22	32.53	31.88	299.56	298.17	298.86
T_{10}	288.41	292.80	290.61	38.49	37.39	37.94	335.41	340.80	338.10
SEm±	9.32	12.31	7.72	2.52	2.06	1.63	22.93	22.82	16.18
CD at 5%	27.70	NS	22.15	NS	NS	NS	NS	NS	46.40
CV (%)	5.84	7.61	6.80	12.16	9.89	11.08	12.89	12.83	12.86
Year									
SEm±			0.32			0.29			1.71
CD at 5%			NS			NS			NS
Y x T									
SEm±			10.92			2.30			22.88
CD at 5%			NS			NS			NS

3.3 Effect on the uptake of nutrients

The mix/intercropping systems showed significant influence on total uptake of N, P and K by mix/intercropping system during 2020-21, 2021-22 and in pooled results (Table 3).

3.3.1 Nitrogen

The treatment T_{10} [Groundnut+ sweet corn (2:1) with paired row (30-60-30 cm)] had significantly the highest total uptake of N by mix/intercropping system (168.51, 168.04 and 168.27 kg/ha)during both the years and in pooled results, respectively. Hence, it may play an important role in promoting nitrogen uptake and transport in the intercropping of groundnutand sweet corn. This might be due significantly highest pod/cob & haulm/fodder yield in these intercropping system and *Bradyrhizobium* promotes nodulation and nitrogen fixation in groundnut during intercropping (Solanki *et al*., 2019; Pang *et al*., 2021; Chen *et al*., 2022).Whereas, significantly the lowest value of total uptake of N by mix/intercropping system (68.61, 73.09 and 70.85 kg/ha) was recorded under the sole groundnut during the year of 2020-21, 2021-22 and in pooled results, respectively (Table 3).

3.3.2 Phosphorus

Significantly the highest total uptake of P by mix/intercropping system (44.95, 46.67 and 45.81 kg/ha) was recorded under the sole sweet corn (T_2) during both the years and in pooled results, respectively (Table 3). This might be due to higher plant density under sole sweet corn as compared to other mix/intercropping systemsresults in more crop yield and total phosphorus uptake by the produce (Mandal *et al.*,2014; Devi and Singh, 2016; Palmo *et al.*, 2024).However, significantly the lowest total uptake of P by mix/intercropping system (8.92, 9.89 and 9.40 kg/ha) was noted under the sole groundnut (T_1) during 2020-21, 2021-22 and in pooled results, respectively.

3.3.3 Potassium

Sole sweet corn (T_2) was significantly recorded the maximum value of total uptake of K by mix/intercropping system (126.32, 137.81 and 132.07 kg/ha) during both the years and in pooled results, respectively (Table 3). This might be due to higher plant density under sole sweet corn as compared to other mix/intercropping systems results in more crop yield and total potassium uptake by the produce (Mandal *et al*.,2014; Devi and Singh, 2016; Palmo *et al*., 2024).While, treatment T_6 [Groundnut + sweet corn (1:1) in additive series] was at par with treatment T_2 during the years 2020-21 and 2021-22. Significantly the lowest uptake of K by mix/intercropping system (42.64, 46.87 and 44.76 kg/ha) was registered under treatment T_1 (Sole groundnut) during the year 2020-21, 2021-22 and in pooled results, respectively.

Table 3. Total uptake of NPK by mix/intercropping systems as influenced by groundnut based mix/intercropping systems

Treatment	Total N uptake (kg/ha)			Total P uptake (kg/ha)			Total K uptake (kg/ha)		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T_1	68.61	73.09	70.85	8.92	9.89	9.40	42.64	46.87	44.76
T_2	151.23	154.45	152.84	44.95	46.67	45.81	126.32	137.81	132.07
T_3	118.77	118.12	118.45	35.96	36.51	36.23	91.68	98.01	94.84
T_4	131.37	143.34	137.36	33.80	39.11	36.46	86.00	103.68	94.84
T_5	103.64	115.74	109.69	24.66	26.93	25.79	63.50	73.60	68.55
T_6	115.83	114.88	115.36	31.67	31.86	31.77	119.57	125.67	122.62
T_7	132.64	137.43	135.03	34.69	38.66	36.68	86.78	99.28	93.03
T_8	125.45	129.42	127.43	28.67	30.17	29.42	70.51	79.06	74.78
T_9	82.98	87.41	85.20	16.51	17.51	17.01	44.07	48.80	46.43
T_{10}	168.51	168.04	168.27	40.20	40.44	40.32	114.16	114.71	114.43
SEm±	4.74	4.20	3.17	1.51	1.91	1.22	3.84	4.84	3.09
CD at 5%	14.08	12.48	9.08	4.49	5.68	3.49	11.40	14.37	8.86
CV (%)	6.84	5.86	6.35	8.72	10.42	9.66	7.87	9.03	8.53
Year									
SEm±			1.04			0.37			1.10
CD at 5%			2.99			1.07			3.15
Y x T									
SEm±			4.48			1.72			4.37
CD at 5%			NS			NS			NS

3.4Balance sheet of nutrients

3.4.1 Nitrogen

Groundnut+ sweet corn (2:1) with paired row (30-60-30cm)(T_{10})shown an increase of 107.18 kg/ha which might be due to the intercropping of leguminous crop *i.e.* groundnut with the sweet corn (Table 4). The highest loss of available nitrogen to the tune of 43.47 kg/ha was recorded under intercropping of groundnut+ sweet corn (1:1) in additive series (T_6) which was followed by sole sweet corn (T_2). Maximum removal of nitrogen may be attributed to greater production of biomass. Higher amounts of nitrogen fertilizer doses are to expect from the intercropping system which have net loss in the available nitrogen.

Table 4. Balance sheet of available nitrogen in soil.

Treatments	Amount added	Initial	Total	Crop uptake	Expected balance	Actual balance	Net gain/loss
T_1	25.00	301.70	326.70	70.85	255.85	292.47	36.62
T_2	100.00	301.70	401.70	152.84	248.86	242.38	-6.48
T_3	62.50	301.70	364.20	118.45	245.75	272.60	26.85
T_4	50.00	301.70	351.70	137.36	214.34	285.48	71.14
T_5	43.75	301.70	345.45	109.69	235.76	287.02	51.26
T_6	125.00	301.70	426.70	115.36	311.34	267.87	-43.47
T_7	75.00	301.70	376.70	135.03	241.67	280.60	38.93
T_8	55.00	301.70	356.70	127.43	229.27	285.62	56.35
T_9	40.00	301.70	341.70	85.20	256.50	278.27	21.77
T_{10}	50.00	301.70	351.70	168.27	183.43	290.61	107.18

3.4.2 Phosphorus

There was a net loss of available phosphorus in all of the intercropping cropping treatments (Table 5). The highest loss of available phosphorus amounting to 64.34 kg/ha was recorded with intercropping of groundnut + sweet corn (1:1) in additive series (T_6) followed by 35.96 kg/ha under (2:1) in additive series (T_7) and (3:1) in additive series (T_8) (34.88 kg/ha). Besides the lowest decline was recorded under groundnut+ sweet corn (2:1) with paired row (30-60-30 cm) (T_{10}) (5.04 kg/ha) followed by sole sweet corn (T_2) (6.56 kg/ha) which might be due to the higher crop density and uptake in these intercropping systems.

Table 5. Balance sheet of available phosphorus in soil.

Treatments	Amount added	Initial	Total	Crop uptake	Expected balance	Actual balance	Net gain/loss
T_1	50.00	33.30	83.30	9.40	73.90	39.82	-34.08
T_2	50.00	33.30	83.30	45.81	37.49	30.93	-6.56
T_3	50.00	33.30	83.30	36.23	47.07	36.34	-10.73
T_4	50.00	33.30	83.30	36.46	46.84	37.70	-9.14
T_5	50.00	33.30	83.30	25.79	57.51	37.97	-19.54
T_6	100.00	33.30	133.30	31.77	101.53	37.19	-64.34
T_7	75.00	33.30	108.30	36.68	71.62	35.66	-35.96
T_8	65.00	33.30	98.30	29.42	68.88	34.00	-34.88
T_9	50.00	33.30	83.30	17.01	66.29	31.88	-34.41
T_{10}	50.00	33.30	83.30	40.32	42.98	37.94	-5.04

3.4.3 Potassium

There was a net gain of available potassium in alltreatments of the groundnut-sweet corn intercropping system (Table 6). The maximum gain of 144.52 kg/ha was recorded under groundnut+ sweet corn (2:1) with paired row (30-60-30 cm) (T_{10}) followed by intercropping of groundnut + sweet corn (2:1) in replacement series (T_4) (108.78 kg/ha) and groundnut + sweet corn (3:1) in additive series (T_8) (107.44 kg/ha)which might be due to the higher biomass production and uptake in these intercropping systems.

Table 6. Balance sheet of available potassium in soil.

Treatments	Amount added	Initial	Total	Crop uptake	Expected balance	Actual balance	Net gain/loss
T_1	0.00	291.35	291.35	44.76	246.59	346.84	100.25
T_2	50.00	291.35	341.35	132.07	209.28	241.39	32.11
T_3	25.00	291.35	316.35	94.84	221.51	277.44	55.93
T_4	16.67	291.35	308.02	94.84	213.18	321.95	108.78
T_5	12.50	291.35	303.85	68.55	235.30	339.05	103.75

T_6	50.00	291.35	341.35	122.62	218.73	283.51	64.78
T_7	25.00	291.35	316.35	93.03	223.32	295.77	72.45
T_8	15.00	291.35	306.35	74.78	231.57	339.01	107.44
T_9	10.00	291.35	301.35	46.43	254.92	298.86	43.94
T_{10}	16.67	291.35	308.02	114.43	193.59	338.10	144.52

Conclusion:

The intercropping of groundnut+ sweet corn (2:1) with paired row (30-60-30 cm) followed by groundnut+ sweet corn (2:1) in replacement series and (3:1) in additive series often leads to higher overall productivity compared to sole cropping, as these intercropping systems improves nutrient cycling in the soil, reducing nutrient losses and enhancing the availability of nutrients like nitrogen and potassium. This is especially beneficial for maintaining long-term soil fertility. This results in better yields without depleting soil fertility.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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