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Pavan Kumar Reddy

y.pavankumarreddy@angrau.ac.in

Agricultural College, Ranga Agricultural University

B. Sahadeva Reddy

RARS, Acharya NG Ranga Agricultural University

P. Radhika

RARS, Acharya NG Ranga Agricultural University

P. Venkata Ramana

Agricultural Research Station, Acharya NG Ranga Agricultural University

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Modelling of variability and relationships of plant parameters for sustainability of groundnut pod and haulm yield under APCNF and ICM in arid alfisols

Y.Pavan Kumar Reddy[1], B.Sahadeva Reddy[2], P. Radhika[3], P.Venkata Ramana[4]

[1]Assistant Professor, Agricultural College, Acharya NG Ranga Agricultural University, Mahanandi, Andhra Pradesh, India.

[2,3] Principal Scientist, RARS, Acharya NG Ranga Agricultural University, Maruteru, Andhra Pradesh, India.

[4]Agricultural Research Station, Acharya NG Ranga Agricultural University, Anantapur, Andhra Pradesh, India.

Email: y.pavankumarreddy@angrau.ac.in

ABSTRACT

Field experiment on groundnut was conducted under APCNF and ICM at Agricultural Research Station, Anantapur under arid alfisols during 2022. Observations were collected on plant population, root length, plant height, shelling, No. of branches, pods and filled pods, 100 pod, kernel and seed weight, pod weight, haulm yield and harvest index. Under APCNF, mean initial (at 120 DAS) pH of 7.6 (7.1), EC of 0.11 ds/m (0.19 ds/m), OC of 0.33% (0.30%), N of 187.9 kg/ha (157.5 kg/ha), P_2O_5 of 40.2 kg/ha (44.9 kg/ha), K_2O of 321.6 kg/ha (439.5 kg/ha) were observed. Under ICM, mean initial (at 120 DAS) pH of 7.3 (7.2), EC of 0.13 ds/m (0.17 ds/m), OC of 0.33% (0.28%), N of 256.6 kg/ha (126.2 kg/ha), P_2O_5 of 44.9 kg/ha (55.8 kg/ha), K_2O of 365.7 kg/ha (264.1 kg/ha) were observed. Under APCNF, mean plant population of 18.8/sq.m, root length of 5.9 cm, plant height of 117.4 cm, shelling of 66.9%, 100 pod weight of 79.7 g, 100 kernel weight of 36.9 g, pod weight of 341 kg/ha, haulm yield of 591 kg/ha, No. of branches of 4.7, pods of 58.5, filled pods of 46.7, 100 seed weight of 0.13 g, harvest index of 0.36% were observed. Under ICM, mean plant population of 24.0/sq.m, root length of 7.6 cm, plant height of 141.5 cm, shelling of 64.1%, 100 pod weight of 58.0 g, 100 kernel weight of 33.9 g, pod weight of 546 kg/ha, haulm yield of 1813 kg/ha, No. of branches of 11.6, pods of 69.5, filled pods of 52.2, 100 seed weight of 0.13 g, harvest index of 0.24% were observed. Significant differences existed between APCNF and ICM for plant population, root length, pod weight, haulm yield, harvest index, plant height and branches, 100 pod and kernel weight. Plant population, root length, pod weight, haulm yield, plant height and branches were higher under ICM, while 100 pod and kernel weight, harvest index were higher under APCNF. Ranks were assigned to the mean values of treatments for different plant parameters under APCNF and ICM. The two groups of plant parameters were viz., plant population, root length, plant height, No. of branches, shelling, No. of pods and No. of filled pods under the 1st rank sum group (RS1); and 100 pod weight, 100 kernel weight, 100 seed weight, pod yield, haulm yield and harvest index under the 2nd rank sum group (RS2). Under APCNF, T12 was superior under RS1 group, while T6 was superior under RS2 group. Based on the combined rank sum, T12 was superior. Under ICM, T1 was superior under RS1 group,

while T3 was superior under RS2 group. Based on the combined rank sum, T3 was superior. Based on soil parameters, T7 was superior under both APCNF and ICM.

Under APCNF, significant positive correlation existed between (i) shelling and 100 pod weight; (ii) 100 kernel weight and harvest index; (iii) pod weight and harvest index; (iv) plant height with No. of branches, pods, filled pods; (v) No. of branches with pods, filled pods; (vi) No. of pods with filled pods. Significant negative correlation existed between (i) shelling and 100 seed weight; (ii) 100 pod and seed weight; (iii) 100 kernel weight and haulm yield. Under ICM, significant positive correlation existed between (i) root length and haulm yield; (ii) shelling and 100 seed weight; (iii) pod weight and harvest index; (iv) plant height with branches, pods; (v) branches with pods, filled pods; (vi) pods and filled pods; while significant negative correlation existed between haulm yield and harvest index. Based on PC analysis, PCs explained 80.9% and 82.1% variance under APCNF and ICM respectively. Under APCNF, plant height, branches, pods and filled pods had significant loadings on PC1; compared to shelling, 100 kernel and seed weight on PC2; root length and haulm yield on PC3; pod weight on PC4. Under ICM, shelling, haulm yield, harvest index, plant height, pods, filled pods had significant loadings on PC1; compared to root length, haulm yield on PC2; 100 pod weight, plant height on PC3; plant population on PC4. Under APCNF, considering loadings on the first PC and CV of parameters, (i) plant height had low CV with significant positive loading; while (ii) harvest index, shelling, root length, 100 kernel, pod and seed weight had low CV with non-significant positive loadings; (iii) plant population had low CV with non-significant negative loading; (iv) No. of branches, pods, filled pods had high CV with significant positive loading; (v) pod weight had high CV with non-significant positive loading; (vi) haulm yield had high CV with non-significant negative loading. Under ICM, considering loadings on the first PC and CV, (i) plant height, shelling had low CV with significant positive loadings; while (ii) branches, 100 seed and kernel weight, root length, plant population had low CV with non-significant positive loadings; (iii) haulm yield, pods and filled pods had high CV with significant positive loadings; (iv) pod weight, 100 pod weight had high CV with non-significant negative loadings; (v) harvest index had high CV with significant negative loading.

Regression model of APCNF included root length, shelling, 100 kernel and seed weight, plant height, No. of branches, pods, filled pods; while ICM model included plant population, root length, shelling, harvest index, plant height, No. of pods, filled pods for predicting pod and haulm yield. ICM model gave R^2 of 0.65 for pod and 0.76 for haulm yield compared to 0.45 and 0.54 under APCNF respectively. Under APCNF, shelling, 100 kernel and seed weight, No. of pods had positive effect, while root length, plant height, branches, filled pods had negative effect on pod yield. Shelling, No. of pods, filled pods, 100 seed weight had positive effect, while root length, 100 kernel weight, plant height, branches had negative effect on haulm yield. Under ICM, plant population, root length, shelling, harvest index, plant height, filled pods had positive effect; while No. of pods had negative effect on pod yield. Plant population, root length, shelling, plant height, filled pods had positive effect, while harvest index and No. of pods had negative effect on haulm yield. Using the (i) mean yield of treatments, (ii) maximum yield attained by any treatment under a category and (iii) prediction error of yield based on the model of the respective category, pod yield has a SYI of 32.1% for attaining maximum yield of 625 kg/ha under APCNF compared to 42.3% for

attaining maximum yield of 960 kg/ha under ICM. Similarly, haulm yield had a SYI of 48.3% for attaining maximum yield of 880 kg/ha under APCNF compared to 44.5% for attaining maximum yield of 3100 kg/ha under ICM. The findings based on the study are applicable to the similar soil and agro-climatic conditions in any region.

Key words: Soil parameters, Plant parameters, Variability, t-test, Correlation, Principal Components, Regression, Sustainability Yield Index, *Alfisols*

INTRODUCTION

Farmers are often guided to increase production by increasing use of fertilizers and pesticides in the conventional farming, which has affected the soil health and fertility. Indiscriminate use of fertilizers and pesticides resulted into decreased soil fertility and thereby decreased sustainability apart from decreased microbial activity and soil and water pollution. For overcoming these problems, natural farming would be the best alternative. Farmers of Anantapur grow groundnut as a major crop during kharif, followed by pigeonpea and other pulses. Of late, farmers are utilizing higher doses of pesticides and fertilizers for different crops. By and large, mono-cropping is prevalent in Anantapur district, causing losses to farmer due to vagaries of monsoon. There is a need to suggest to farmers for less dependence on chemicals and switch over to naturally available inputs. In natural farming, neither chemical nor organic fertilizers are added to the soil or plants. There are many constraints under the rainfed ecosystems viz., low and erratic rainfall, low moisture, degraded and poor resource base, soil fertility decline and low productivity. These factors would lead to the over-exploitation of existing natural resources and increase the speed of degradation. Maintenance of soil health is a significant activity for increasing the crop productivity, apart from having feasible technologies for sustaining the productivity for a long period. Monocropping is adopted in rainfed regions due to lack of sufficient soil moisture.

Zero Budget Natural Farming is a method of farming where the cost of growing and harvesting the plants would be zero. This indicates that farmers need not purchase fertilizers and pesticides for growing healthy crops. Locally available natural biodegradable materials saturated with scientific knowledge of ecology and modern technology with traditional farming practices based on naturally occurring biological processes could be adopted. This type of farming was suggested by Shri Subhash Palekar, for which he was honoured with Padma Shri in 2016 (Anon., 2016). The practice of introducing cover crops in a fallow soil rather than leaving the land vegetation-free would greatly help in controlling erosion and runoff control, biological fixation of N, higher utilization of applied N, enhanced soil productivity and fertility, weed suppression, reduction in greenhouse gas (GHG) emissions (Srinivasa Rao et al., 2022). Growing cover crops either before or between main crops would enhance the soil physical, chemical and biological properties and subsequently would improve soil health and productivity of crops (Indoria *et al*., 2018, 2017; Kundu *et al*., 2016). Further, the cover crops would significantly reduce the evaporation losses from the soil surface, safeguard the soil moisture from the rainfall and irrigation, apart from improving the soil moisture availability to the succeeding crops (Kundu *et al*., 2013).

PMDS is a system of sowing, tilling and tending the land wherein the farmer can grow crops in the non-

farming season or whenever there is no crop cover on the land. This is mostly before the advent of monsoon, during summers, and before beginning of the rabi season. This system believes that land should always be covered and farmers should not depend on the rainy season only for growing crops, which is predominantly the case of farming in India. Compared to the average paid-out cost of ₹.21139/ha, and average returns, of all known benefits of ₹.39075/ha, the surplus from PMDS cultivation, at the state level, have increased to ₹.17935/ha (Report on assessing the impact of APCNF). PMDS cultivation is not completely aimed at the economic returns, over 71% of sample farmers have harvested some crop or the other. Even after meeting all the costs of own inputs used, including the value of own labour and the cost of all purchased inputs, except Krishna zone and SC farmers, all zones and farmers' categories recorded surplus. This indicated that the PMDS has good potential to generate economic, if not financial, surpluses over and above the total costs (Assessment and impact of APCNF, 2022).

The mulching material which would be spread across the field as a part of PMDS, would act as the catalyst to harness the water vapour from the atmosphere that drops to the land surface in the form of early morning dew. The material would facilitate the percolation of the dew into the soil and prevents its evaporation. Farmers grow PMDS during March-May/June, followed by kharif crops, pre-rabi dry sowing (PRDS) and rabi crops under the CNF scheme. The crops grown in PMDS and PRDS are used as green manure, after intermittently attaining some cash income and food items to the farmers and green fodder to the animals (Report on assessing the impact of APCNF). The zero budget farmers would use mulching, soil protection techniques, natural pesticides and fertilizers. The principal methods of ZBNF include crop rotation, green manures and compost, biological pest control and mechanical cultivation. There are four pillars of ZBNF i.e., Jivamrita, Bijamrita, Acchadana and Whapasa, which we will discuss later (Ruchi Bishnoi and Akshaya Bhati, 2017).

In a study by Maruthi Sankar et al., (2014), the authors assessed the efficiency of fertilizer treatments with a given rainfall for attaining maximum crop yield and enhancing the soil fertility, the principal component (PC) analysis was considered as one of the most robust methods. Parama et al., (2018) assessed the variability and relationships of different soil fertility parameters based on the PC analysis and identified superior parameters for capturing maximum variability in the data under semi-arid alfisols. The PC analysis reduces the dimensionality from a large number of variables to a few significant principal components for explaining maximum variability in the data (Dunteman, 1989). The PC models could be used for assessing the efficiency of input treatments (Norris, 1972; Jolliffe, 1986). This procedure could also be used to assess the changes in the plant and soil parameters over years under different soil and agro-climatic conditions. A reduction in the dimensionality is of important economic consideration, especially if the potential information recoverable from the transformed data is as good as the original data (Anderson and Furley, 1975). The present study was undertaken at ANGRAU, Anantapur, Andhra Pradesh with the objective to assess the variability and relationships of different plant growth parameters observed under APCNF and ICM categories. Based on the principal component analysis, significant plant parameters were identified for developing yield prediction models. Regression models were developed to predict the pod and haulm yields through the significant parameters identified based on PC analysis.

MATERIALS AND METHODS

A field study was conducted with groundnut under APCNF and groundnut + pigeonpea (8:1) under ICM categories at Agricultural Research Station, Acharya NG Ranga Agricultural University, Anantapur during 2022. The study was conducted with the objective to assess the variability and relationships of different plant parameters under APCNF and ICM categories. The location had a red sandy loam soil having neutral pH in reaction and good EC. The soil was medium in available nitrogen, high in available phosphorus and high in available potassium. The micro nutrients are above critical level expect copper. The site of experimentation was previously grown with castor crop. Cow dung was the key component in APCNF 365 days treatment. Hence the cow dung quantity was standardised based on four cows for a period of one month continuously.

The field experiments were conducted under the arid alfisols with normal rainfall of 590.6 mm from 36 rainy days. During 2022, there location received annual rainfall of 818.4 mm from 45 rainy days. The monthly distribution of rainfall and rainy days is depicted in Fig 1. August month received maximum rainfall of 260.8 mm (9 rainy days), followed by October with rainfall of 136.6 mm (9 rainy days), June with 136.0 mm (7 rainy days), September with 111.8 mm (6 rainy days), May with 55.4 mm (5 rainy days), July with 55.0 mm (3 rainy days), December with 44.6 mm (3 rainy days), November with 14.2 mm (2 rainy days) and April with 4.0 mm (1 rainy day). Groundnut was sown on 27th July 2022, while it was harvested on 16th November 2022 under APCNF and 1st December 2022 under ICM categories. Thus, the crop had a duration of 111 days under the APCNF and 160 days under the ICM categories. The crop grown under both categories faced two dry spells at vegetative and flowering phase for a period of 19 days in August and 20 days in September. Observations were collected on 13 plant parameters viz., plant population, root length (cm), plant height (cm), No. of branches, shelling (%), No. of pods, No. of filled pods, 100 pod weight (g), 100 kernel weight (g), 100 seed weight (g), pod weight (kg/ha), haulm yield (kg/ha) and harvest index (%). The net plot size in the study was (4 x 5 m^2). The initial bulk density under APCNF was 1.41 g/cc compared to 1.39 g/cc on 45 DAS. Under ICM, the bulk density was 1.41 and 1.40 g/cc at initial and 45 DAS respectively. The initial water holding capacity under APCNF was 33% compared to 38% on 45 DAS. Under ICM, the water holding capacity was 33% and 36% at initial and 45 DAS respectively.

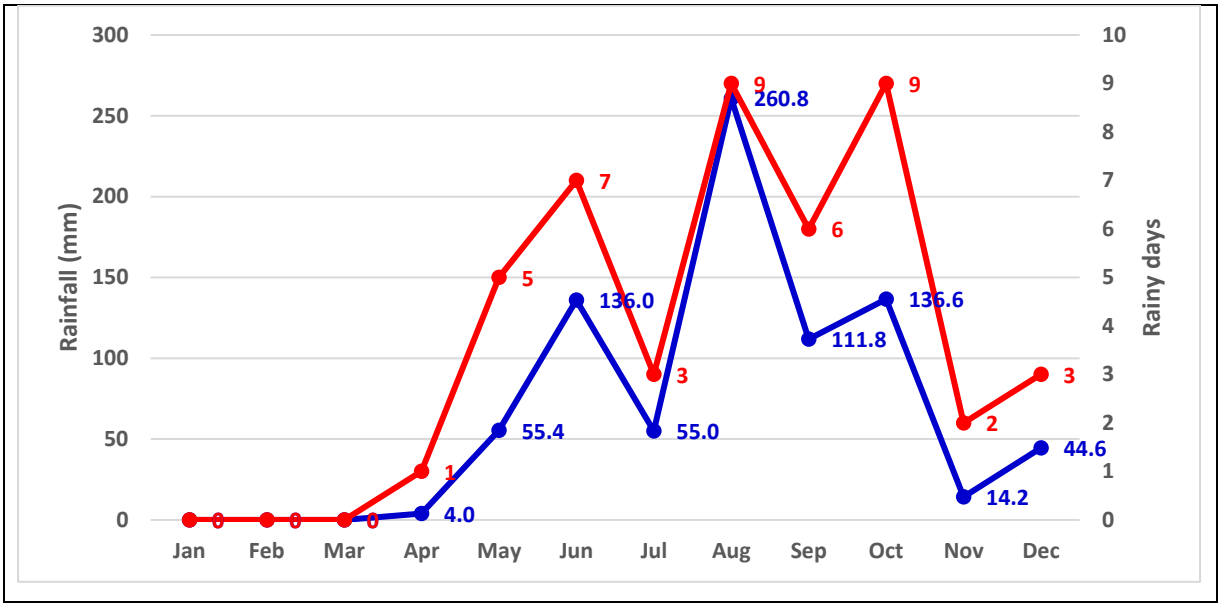


Fig 1. Distribution of monthly rainy days and rainfall received at Anantapur during 2022

Descriptive statistics viz., minimum, maximum, mean, standard deviation and coefficient of variation were derived for each parameter under the two categories. The differences of parameters between the two categories were tested based on the Student's t-test at 5% and 1% level of significance. Estimates of correlation were derived between different pairs of parameters under each category and were tested for significance (Gomez and Gomez, 1984). Ranks were assigned to the mean and coefficient of variation under two groups of parameters viz., RS1 and RS2 separately for APCNF and ICM categories and rank sums were derived. Among plant parameters, plant population, root length (cm), plant height (cm), No. of branches, shelling (%), No. of pods and No. of filled pods were included in the 1st rank sum group (RS1), while 100 pod weight (g), 100 kernel weight (g), 100 seed weight (g), pod weight (kg/ha), haulm yield (kg/ha) and harvest index (%) were included in the 2nd rank sum group (RS2). Based on the rank sums of mean and CV values of plant parameters, the superiority of APCNF and ICM categories were assessed.

The estimates of correlation derived between different plant parameters were used to derive the principal components (PC) of parameters under APCNF and ICM categories (Dunteman George, 1989; Jolliffe, 1986; Norris, 1972). A significant PC will have an eigen value more than '1'. The total variance (%) explained by the significant principal components was assessed by considering the eigen values of significant PCs under APCNF and ICM categories. The parameters were assessed based on their loadings on PCs. Based on the PC analysis, a plant parameter is considered as significant if it has a positive loading of either more than +0.60 or negative loading of less than -0.60. An assessment was made by comparing (i) the loadings of parameters on the principal components and (ii) the coefficient of variation of parameters observed under APCNF and ICM categories. Significant plant parameters were identified based on the loadings of parameters on the PCs and their variability.

Regression models were calibrated to predict the pod yield and haulm yield through the significant parameters which have a positive loading of either more than +0.60 or negative loading of less than -0.60 as identified based on the PC analysis. The models were assessed for superiority based on the estimates of coefficient

of determination (R^2) and prediction error (PE) for pod yield and haulm yield derived under APCNF and ICM categories (Maruthi Sankar, 1986; Draper and Smith, 1998).

RESULTS AND DISCUSSION

Descriptive statistics of plant growth parameters under APCNF

The effects of 15 treatments on plant growth parameters under APCNF viz., plant population, root length, shelling, plant height, No. of branches, No. of pods and No. of filled pods under APCNF along with the descriptive statistics are given in Table 1. The plant population ranged from 10 (T8) to 25 (T1) with mean of 18.8 (Coefficient of variation of 20.0%), while the root length ranged from 4.1 cm (T6) to 7.6 cm (T12) with mean of 5.9 cm (CV of 17.7%). The plant height ranged from 94.6 cm (T3) to 140.3 cm (T1) with mean of 117.4 cm (CV of 12.2%), while the shelling (%) ranged from 56% (14) to 78% (T6) with mean of 67% (CV of 7.4%). The No. of branches ranged from 2.6 (T4) to 7.6 (T12) with mean of 4.7 (CV of 29.9%), while the No. of pods ranged from 22.6 (T5) to 107.8 (T15) with mean of 58.5 (CV of 46.3%). The No. of filled pods ranged from 18.2 (T5) to 84.8 (T15) with mean of 46.7 (CV of 49.7%). T1, T3, T4, T5, T9, T10, T13, T14 and T15 gave above average plant population; while T1, T2, T3, T5, T8, T10, T12 and T13 gave above average root length. T1, T2, T3, T4, T6, T7, T9 and T12 gave above average shelling; while T1, T6, T7, T11, T12, T13 and T15 gave above average plant height. T1, T2, T7, T8, T11, T12 and T15 gave above average No. of branches; while T7, T9, T11, T12, T13 and T15 gave above average No. of pods and No. of filled pods.

Table 1. Treatment-wise plant growth parameters of groundnut under APCNF during 2022

Treatments	Population	Root length	Shelling	Plant height	No. of branches	No. of pods	No. of filled pods
T1	25	6.8	68	140.3	5.0	55.6	44.0
T2	18	7.2	72	113.3	4.8	44.0	26.0
T3	19	6.8	68	94.6	3.0	27.0	21.4
T4	21	4.7	68	103.0	2.6	32.8	27.4
T5	23	6.5	62	111.4	4.0	22.6	18.2
T6	17	4.1	78	117.6	4.2	35.2	24.8
T7	14	4.8	70	136.1	5.4	86.6	72.6
T8	10	6.9	66	116.3	4.8	56.6	40.4
T9	20	5.2	68	117.0	4.2	61.2	51.8
T10	21	6.0	66	102.5	4.0	51.4	45.0
T11	18	5.4	64	123.9	6.4	82.0	67.4
T12	15	7.6	70	134.4	7.6	95.4	78.6
T13	19	6.2	64	124.9	4.4	86.4	73.0
T14	20	5.4	56	95.9	3.0	33.6	25.2
T15	22	5.0	64	129.7	6.6	107.8	84.8
Minimum	*10*	*4.1*	*56*	*94.6*	*2.6*	*22.6*	*18.2*
Maximum	*25*	*7.6*	*78*	*140.3*	*7.6*	*107.8*	*84.8*
Mean	*18.8*	*5.9*	*67*	*117.4*	*4.7*	*58.5*	*46.7*
SD	*3.8*	*1.0*	*4.9*	*14.3*	*1.4*	*27.1*	*23.2*
CV (%)	*20.0*	*17.7*	*7.4*	*12.2*	*29.9*	*46.3*	*49.7*

SD: Standard deviation CV: Coefficient of variation (%)

Descriptive statistics of yield parameters under APCNF

The effects of 15 treatments on yield parameters under APCNF viz., 100 pod weight, 100 kernel weight,

100 seed weight, pod yield, haulm yield and harvest index along with the descriptive statistics are given in Table 2. The 100 pod weight ranged from 64 g (T11) to 94 g (T9) with mean of 79.7 g (CV of 10.4%), while the 100 kernel weight ranged from 28 g (T15) to 44 g (T2) with mean of 36.9 g (CV of 12.3%). The pod yield ranged from 195 kg/ha (T3) to 625 kg/ha (T6) with mean of 341 kg/ha (CV of 36.5%), while the haulm yield ranged from 338 kg/ha (T3) to 880 kg/ha (T10) with mean of 591 kg/ha (CV of 27.2%). The 100 seed weight ranged from 0.12 to 0.14 g with mean of 0.13 (CV of 8.0%). The harvest index ranged from 0.24 (T9) to 0.47 (T1) with mean of 0.36 (CV of 20.7%). T1, T2, T4, T6, T7, T8, T9 and T12 gave above average 100 pod weight; while T1, T2, T4, T6, T7, T11, T12 and T13 gave above average 100 kernel weight. T1, T5, T10, T11, T12, T13, T14 and T15 gave above average 100 seed weight; while T1, T2, T3, T6, T7, T8, T11, T12 and T13 gave above average harvest index. T1, T6, T10, T11, T12 and T13 gave above average pod yield; while T6, T9, T10, T11, T12 and T14 gave above average haulm yield.

Table 2. Treatment-wise yield parameters of groundnut under APCNF during 2022

Treatments	100 pod weight	100 kernel weight	100 seed weight	Pod yield	Haulm yield	Harvest index
T1	80	40	0.14	420	475	47
T2	88	44	0.12	308	390	44
T3	74	36	0.12	195	338	37
T4	80	38	0.12	248	525	32
T5	76	36	0.14	230	465	33
T6	90	38	0.12	625	820	43
T7	82	42	0.12	300	460	39
T8	90	34	0.12	310	540	36
T9	94	36	0.12	225	725	24
T10	72	30	0.14	483	880	35
T11	64	40	0.14	478	610	44
T12	84	38	0.14	405	610	40
T13	74	42	0.12	405	570	42
T14	72	32	0.14	273	805	25
T15	76	28	0.14	205	650	24
Minimum	*64*	*28*	*0.12*	*195*	*338*	*24*
Maximum	*94*	*44*	*0.14*	*625*	*880*	*47*
Mean	*79.7*	*36.9*	*0.13*	*341*	*591*	*36*
SD	*8.3*	*4.5*	*0.01*	*124*	*161*	*7*
CV (%)	*10.4*	*12.3*	*8.0*	*36.5*	*27.2*	*20.7*

SD: Standard deviation CV: Coefficient of variation (%)

Descriptive statistics of plant growth parameters under ICM

The effects of 15 treatments on plant growth parameters under ICM viz., plant population, root length, shelling, plant height, No. of branches, No. of pods and No. of filled pods along with the descriptive statistics are given in Table 3. The plant population ranged from 16 (T4) to 36 (T1) with mean of 24.0 (CV of 23.3%), while the root length ranged from 6.1 cm (T9) to 9.4 cm (T3) with mean of 7.6 cm (CV of 15.9%). The plant height ranged from 108.6 cm (T14) to 168.1 cm (T3) with mean of 141.5 cm (CV of 11.2%), while the shelling (%) ranged from 50% (T15) to 72% (T6) with mean of 64% (CV of 9.8%). The No. of branches ranged from 7.4 (T14) to 14.6 (T4) with mean of 11.6 (CV of 18.8%), while the No. of pods ranged from 10.8 (T14) to 125.4 (T10) with mean of 69.5 (CV of 47.1%). The No. of filled pods ranged from 8.4 (T14) to 95.8 (T10) with mean of 52.2 (CV of 50.7%). T1,

T2, T3, T5, T7, T9, T12, T14 and T15 gave above average plant height; while T1, T3, T5, T6, T7 and T13 gave above average root length. T1, T2, T3, T4, T5, T7, T9 and T10 gave above average plant height; while T1, T2, T3, T6, T7, T11, T12 and T13 gave above average shelling. T1, T2, T3, T4, T9, T10, T11 and T12 gave above average No. of branches; while T1, T4, T6, T7, T10 and T11 gave above average No. of pods; and T1, T4, T6, T7, T10 and T11 gave above average No. of filled pods.

Table 3. Treatment-wise plant growth parameters of groundnut under ICM during 2022

Treatments	Population	Root length	Shelling	Plant height	No. of branches	No. of pods	No. of filled pods
T1	36	8.2	68	148.2	14.6	89.2	75.0
T2	34	7.5	68	158.1	14.0	64.8	43.6
T3	24	9.4	66	168.1	11.6	59.8	42.2
T4	16	6.2	62	153.2	14.6	103.0	79.0
T5	24	8.8	62	147.8	8.8	55.4	33.6
T6	20	9.3	72	138.5	8.8	116.4	89.8
T7	25	9.1	70	145.6	11.4	87.8	64.6
T8	18	7.5	58	131.8	10.6	26.4	15.2
T9	28	6.1	62	147.3	11.8	63.2	39.0
T10	20	6.3	58	160.4	14.0	125.4	95.8
T11	18	6.7	72	135.2	12.4	95.0	75.2
T12	24	6.5	68	125.0	12.4	59.8	50.2
T13	22	8.5	68	126.7	10.8	41.0	32.8
T14	25	6.7	58	108.6	7.4	10.8	8.4
T15	26	6.9	50	128.7	10.8	45.0	38.0
Minimum	*16*	*6.1*	*50*	*108.6*	*7.4*	*10.8*	*8.4*
Maximum	*36*	*9.4*	*72*	*168.1*	*14.6*	*125.4*	*95.8*
Mean	*24*	*7.6*	*64.1*	*141.5*	*11.6*	*69.5*	*52.2*
SD	*5.6*	*1.2*	*6.2*	*15.8*	*2.2*	*32.7*	*26.4*
CV (%)	*23.3*	*15.9*	*9.8*	*11.2*	*18.8*	*47.1*	*50.7*

SD: Standard deviation CV: Coefficient of variation (%)

Descriptive statistics of yield parameters under ICM

The effects of 15 treatments on yield parameters under ICM viz., 100 pod weight, 100 kernel weight, 100 seed weight, pod yield, haulm yield and harvest index along with the descriptive statistics are given in Table 4. The 100 pod weight ranged from 9 g (T6) to 94 g (T7) with mean of 58.0 g (CV of 60.9%), while the 100 kernel weight ranged from 28 g (T13) to 38 g (T3, T7) with mean of 33.9 g (CV of 9.1%). The pod yield ranged from 340 kg/ha (T4) to 960 kg/ha (T3) with mean of 545 kg/ha (CV of 30.5%), while the haulm yield ranged from 1000 kg/ha (T11) to 3100 kg/ha (T1) with mean of 1813 kg/ha (CV of 34.7%). The 100 seed weight ranged from 0.10 (T8, T10, T15) to 0.14 g (T1, T2, T4, T5, T6, T11, T12) with mean of 0.13 (CV of 12.70%). The harvest index ranged from 14% (T1) to 34% (T11, T14) with mean of 24% (CV of 29.6%). T1, T3, T4, T5, T7, T9, T10, T13, T14 and T15 gave above average 100 pod weight; while T2, T3, T4, T6, T7, T8, T9, T12 and T15 gave above average 100 kernel weight. T1, T2, T3, T4, T5, T6, T7, T9, T11, T12, T13 and T14 gave above average 100 seed weight; while T3, T5, T8, T9, T10, T11, T12, T13, T14 and T15 gave above average harvest index. T3, T9 and T14 gave above average pod yield; while T1, T2, T3, T6 and T7 gave above average haulm yield.

Table 4. Treatment-wise yield parameters of groundnut under ICM during 2022

Treatments	100 pod weight	100 kernel weight	100 seed weight	Pod yield	Haulm yield	Harvest index
T1	75	32	0.14	488	3100	14
T2	11	36	0.14	510	2250	18
T3	90	38	0.12	960	2500	28
T4	86	36	0.14	340	1650	17
T5	82	32	0.14	489	1500	25
T6	9	36	0.14	498	2950	14
T7	94	38	0.12	357	2150	14
T8	10	36	0.10	483	1400	26
T9	76	36	0.12	750	1500	33
T10	80	32	0.10	494	1250	28
T11	10	30	0.14	525	1000	34
T12	11	34	0.14	505	1550	25
T13	82	28	0.12	472	1450	25
T14	80	30	0.12	810	1600	34
T15	74	34	0.10	500	1350	27
Minimum	*9*	*28*	*0.10*	*340*	*1000*	*14*
Maximum	*94*	*38*	*0.14*	*960*	*3100*	*34*
Mean	*58*	*34*	*0.12*	*545*	*1813*	*24*
SD	*35.3*	*3.1*	*0.02*	*166*	*630*	*7*
CV (%)	*60.9*	*9.1*	*12.7*	*30.5*	*34.7*	*29.6*

SD: Standard deviation CV: Coefficient of variation (%)

Descriptive statistics of soil parameters under APCNF

The descriptive statistics of different soil parameters under APCNF are given in Table 5. Under APCNF category, the initial soil pH ranged from 7.1 (T2, T7) to 7.9 (T6, T11, T15) with mean of 7.6 (CV of 3.6%), while the pH on 120 days after sowing (DAS) ranged from 6.8 (T7) to 7.3 (T9) with mean of 7.1 (CV of 1.9%). The initial electrical conductivity ranged from 0.08 ds/m (T15) to 0.14 ds/m (T13) with mean of 0.11 ds/m (CV of 13.3%), while the EC on 120 DAS ranged from 0.15 ds/m (T15) to 0.22 ds/m (T5, T9) with mean of 0.19 (CV of 10.3%). The initial organic carbon ranged from 0.27% (T2, T6) to 0.38% (T4, T7) with mean of 0.33% (CV of 11.2%), while the organic carbon on 120 DAS ranged from 0.15% (T2) to 0.46% (T1) with mean of 0.30 (CV of 29.7%). The initial N ranged from 174.9 kg/ha (T1) to 199.0 kg/ha (T7, T12, T14) with mean of 187.9 kg/ha (CV of 4.6%), while the N on 120 DAS ranged from 117.0 kg/ha (T1) to 189.2 kg/ha (T13) with mean of 157.5 kg/ha (CV of 14.8%). The initial P_2O_5 ranged from 27.9 kg/ha (T11) to 46.9 kg/ha (T7) with mean of 40.2 kg/ha (CV of 13.1%), while the P_2O_5 on 120 DAS ranged from 21.2 kg/ha (T9) to 72.4 kg/ha (T5) with mean of 44.9 kg/ha (CV of 30.3%). The initial K_2O ranged from 176.0 kg/ha (T8) to 571.6 kg/ha (T14) with mean of 321.6 kg/ha (CV of 33.5%), while the K_2O on 120 DAS ranged from 290.7 kg/ha (T12) to 602.1 kg/ha (T2) with mean of 439.5 kg/ha (CV of 17.9%).

Descriptive statistics of soil parameters under ICM

The descriptive statistics of different soil parameters under ICM are given in Table 5. Under ICM category, the initial soil pH ranged from 6.8 (T15) to 7.9 (T9) with mean of 7.3 (CV of 4.5%), while the pH on 120 DAS ranged from 7.0 (T1) to 7.7 (T5) with mean of 7.2 (CV of 2.8%). The initial electrical conductivity ranged from 0.10 ds/m (T3) to 0.18 ds/m (T7) with mean of 0.13 ds/m (CV of 16.0%), while the EC on 120 DAS ranged from 0.02 ds/m (T15) to 0.28 ds/m (T13) with mean of 0.17 (CV of 32.8%). The initial organic carbon ranged from 0.25% (T3) to 0.40% (T14) with mean of 0.33% (CV of 14.6%), while the organic carbon on 120 DAS ranged from

0.08% (T8, T11) to 0.49% (T6) with mean of 0.28 (CV of 41.5%). The initial N ranged from 181.4 kg/ha (T1) to 298.5 kg/ha (T9) with mean of 256.6 kg/ha (CV of 16.4%), while the N on 120 DAS ranged from 78.7 kg/ha (T8) to 174.8 kg/ha (T6) with mean of 126.2 kg/ha (CV of 21.8%). The initial P_2O_5 ranged from 36.8 kg/ha (T7) to 51.8 kg/ha (T2) with mean of 44.9 kg/ha (CV of 10.4%), while the P_2O_5 on 120 DAS ranged from 41.3 kg/ha (T7, T14) to 72.0 kg/ha (T4) with mean of 55.8 kg/ha (CV of 17.2%). The initial K_2O ranged from 312.2 kg/ha (T9) to 414.8 kg/ha (T3) with mean of 365.7 kg/ha (CV of 8.8%), while the K_2O on 120 DAS ranged from 138.1 (T6) to 462.9 kg/ha (T11) with mean of 264.1 kg/ha (CV of 41.6%).

Table 5. Descriptive statistics of different soil parameters under APCNF and ICM categories during 2022

Parameter	APCNF					ICM				
	Minimum	Maximum	Mean	SD	CV	Minimum	Maximum	Mean	SD	CV
pH (Initial)	7.1	7.9	7.6	0.3	3.6	6.8	7.9	7.3	0.3	4.5
pH (120 DAS)	6.8	7.3	7.1	0.1	1.9	7.0	7.7	7.2	0.2	2.8
EC (ds/m) (Initial)	0.08	0.14	0.11	0.02	13.3	0.10	0.18	0.13	0.02	16.0
EC (ds/m) (120 DAS)	0.15	0.22	0.19	0.02	10.3	0.02	0.28	0.17	0.06	32.8
OC (%) (Initial)	0.27	0.38	0.33	0.04	11.2	0.25	0.40	0.33	0.05	14.6
OC (%) (120 DAS)	0.15	0.46	0.30	0.09	29.7	0.08	0.49	0.28	0.12	41.5
N (kg/ha) (Initial)	174.9	199.0	187.9	8.7	4.6	181.4	298.5	256.6	42.0	16.4
N (kg/ha) (120 DAS)	117.0	189.2	157.5	23.4	14.8	78.7	174.8	126.2	27.5	21.8
P_2O_5 (kg/ha) (Initial)	27.9	46.9	40.2	5.3	13.1	36.8	51.8	44.9	4.7	10.4
P_2O_5 (kg/ha) (120 DAS)	21.2	72.4	44.9	13.6	30.3	41.3	72.0	55.8	9.6	17.2
K_2O (kg/ha) (Initial)	176.0	571.6	321.6	107.7	33.5	312.2	414.8	365.7	32.2	8.8
K_2O (kg/ha) (120 DAS)	290.7	602.1	439.5	78.5	17.9	138.1	462.9	264.1	109.8	41.6

EC: Electrical conductivity OC: Organic carbon N: Nitrogen P_2O_5: Phosphorus K_2O: Potassium
SD: Standard deviation CV: Coefficient of variation (%)

Testing of differences between parameters observed under APCNF and ICM categories

The mean differences between plant parameters observed under APCNF and ICM categories were tested based on t-test and the significances at 5% and 1% level of significance are given in Table 6. Significant mean differences were observed between the APCNF and ICM categories for plant population, root length, pod weight, haulm yield, harvest index, plant height and No. of branches at 1% level of significance. However, the differences between the two categories were significant at 5% level of significance for 100 pod weight and 100 kernel weight. There was no significant difference between the two categories for shelling, No. of pods, No. of filled pods and 100 seed weight. The mean plant population, root length, pod weight, haulm yield, plant height and No. of branches was found to be significantly higher under ICM compared to APCNF category, while the mean 100 pod weight, 100 kernel weight and harvest index was significantly higher under APCNF compared to ICM category.

Table 6. Testing of mean differences of parameters observed under APCNF and ICM categories during 2022

Parameter	APCNF		ICM		SEM	t-calculated
	Mean	SD	Mean	SD		
Plant population	18.8	3.8	24.0	5.6	1.75	-2.976**
Root length (cm)	5.9	1.0	7.6	1.2	0.40	-4.215**
Shelling (%)	66.9	4.9	64.1	6.3	2.06	1.359
100 pod weight (g)	79.7	8.3	58	35.3	9.36	2.318*
100 kernel weight (g)	36.9	4.5	33.9	3.1	1.41	2.126*
Pod yield (kg/ha)	341	124	545	166	53.64	-3.816**
Haulm yield (kg/ha)	591	161	1813	630	167.89	-7.281**
Harvest index (%)	36	8	24	7	0.03	4.372**

Plant height (cm)	117.4	14.3	141.5	15.8	5.50	-4.380**
No. of branches	4.7	1.4	11.6	2.2	0.67	-10.248**
No. of pods	58.5	27.1	69.5	32.7	10.97	-1.003
No. of filled pods	46.7	23.2	52.2	26.5	9.09	-0.605
100 seed weight (g)	0.13	0.01	0.13	0.02	0.01	0.001

t-critical value for 28 degrees of freedom at 5% level of significance = 2.056
t-critical value for 28 degrees of freedom at 1% level of significance = 2.779
SD: Standard deviation SEM: Standard error of mean difference

Relationship between plant parameters under APCNF and ICM categories

The estimates of correlation between different pairs of parameters under APCNF and ICM categories along with their significances are given in Table 7. Under APCNF category, significant positive correlation was observed between (i) shelling and 100 pod weight (0.625); (ii) 100 kernel weight and harvest index (0.732); (iii) pod weight and harvest index (0.641); (iv) plant height with No. of branches (0.790), No. of pods (0.745) and No. of filled pods (0.723); (v) No. of branches with No. of pods (0.830) and No. of filled pods (0.787); (vi) No. of pods with No. of filled pods (0.989). Compared to this, significant negative correlation was observed between (i) shelling and 100 seed weight (-0.518); (ii) 100 pod weight and 100 seed weight (-0.568); and (iii) 100 kernel weight and haulm yield (-0.540).

Under ICM category, significant positive correlation was observed between (i) root length and haulm yield (0.636); (ii) shelling and 100 seed weight (0.707); (iii) pod weight and harvest index (0.595); (iv) plant height with No. of branches (0.588) and No. of pods (0.572); (v) No. of branches with No. of pods (0.531) and No. of filled pods (0.544); (vi) No. of pods and No. of filled pods (0.985); while significant negative correlation was observed between haulm yield and harvest index (-0.712).

Table 7. Correlation between different plant parameters under APCNF and ICM categories during 2022

Plant parameter-1	**Plant parameter-2**	**APCNF**	**ICM**
Plant population	Root length (cm)	-0.093	0.143
	Shelling (%)	-0.288	0.082
	100 pod weight (g)	-0.381	0.110
	100 kernel weight (g)	-0.189	0.050
	Pod weight (kg/ha)	-0.139	0.188
	Haulm yield (kg/ha)	0.063	0.504
	Harvest index (%)	-0.189	-0.236
	Plant height (cm)	-0.112	0.148
	No. of branches	-0.272	0.206
	No. of pods	-0.234	-0.172
	No. of filled pods	-0.189	-0.165
	100 seed weight (g)	0.456	0.192
Root length (cm)	Shelling (%)	-0.108	0.456
	100 pod weight (g)	0.004	0.109
	100 kernel weight (g)	0.159	0.217
	Pod weight (kg/ha)	-0.127	0.036
	Haulm yield (kg/ha)	-0.463	0.636*
	Harvest index (%)	0.338	-0.494
	Plant height (cm)	0.056	0.224
	No. of branches	0.222	-0.327
	No. of pods	-0.018	0.028
	No. of filled pods	-0.051	0.006
	100 seed weight (g)	0.193	0.161

Shelling (%)	100 pod weight (g)	0.625*	-0.339
	100 kernel weight (g)	0.443	0.046
	Pod weight (kg/ha)	0.435	-0.125
	Haulm yield (kg/ha)	-0.113	0.464
	Harvest index (%)	0.509	-0.403
	Plant height (cm)	0.279	0.178
	No. of branches	0.152	0.166
	No. of pods	-0.016	0.408
	No. of filled pods	-0.051	0.407
	100 seed weight (g)	-0.518*	0.707**
100 pod weight (g)	100 kernel weight (g)	0.189	-0.059
	Pod weight (kg/ha)	-0.034	0.172
	Haulm yield (kg/ha)	-0.030	-0.001
	Harvest index (%)	-0.028	0.033
	Plant height (cm)	0.187	0.221
	No. of branches	0.011	-0.010
	No. of pods	-0.088	-0.047
	No. of filled pods	-0.143	-0.061
	100 seed weight (g)	-0.568*	-0.284
100 kernel weight (g)	Pod weight (kg/ha)	0.231	0.057
	Haulm yield (kg/ha)	-0.540*	0.404
	Harvest index (%)	0.732**	-0.404
	Plant height (cm)	0.360	0.513
	No. of branches	0.089	0.171
	No. of pods	0.017	0.191
	No. of filled pods	0.003	0.110
	100 seed weight (g)	-0.444	-0.043
Pod weight (kg/ha)	Haulm yield (kg/ha)	0.471	0.094
	Harvest index (%)	0.641**	0.595*
	Plant height (cm)	0.271	0.034
	No. of branches	0.240	-0.321
	No. of pods	0.096	-0.403
	No. of filled pods	0.100	-0.426
	100 seed weight (g)	0.122	-0.163
Haulm yield (kg/ha)	Harvest index (%)	-0.362	-0.712**
	Plant height (cm)	-0.144	0.341
	No. of branches	-0.012	0.091
	No. of pods	0.081	0.275
	No. of filled pods	0.114	0.286
	100 seed weight (g)	0.309	0.390
Harvest index (%)	Plant height (cm)	0.399	-0.316
	No. of branches	0.256	-0.299
	No. of pods	0.039	-0.450
	No. of filled pods	0.015	-0.459
	100 seed weight (g)	-0.116	-0.382
Plant height (cm)	No. of branches	0.790**	0.588*
	No. of pods	0.745**	0.572*
	No. of filled pods	0.723**	0.476
	100 seed weight (g)	0.157	0.107
No. of branches	No. of pods	0.830**	0.531*
	No. of filled pods	0.787**	0.544*
	100 seed weight (g)	0.390	0.156
No. of pods	No. of filled pods	0.989**	0.985**
	100 seed weight (g)	0.197	0.297
No. of filled pods	100 seed weight (g)	0.216	0.300

Critical correlation value for 13 degrees of freedom at 5% level of significance = 0.514

Critical correlation value for 13 degrees of freedom at 1% level of significance = 0.641
* and ** indicate significance at 5% and 1% level respectively

Eigen values and variance explained by principal components through plant parameters

Based on the principal component (PC) analysis, PCs were determined through different plant parameters under APCNF and ICM categories. The significant PCs which have eigen value of more than '1' and variance explained by the PCs under each category are given in Table 8. Four PCs were found to be significant under APCNF with eigen values ranging from 1.664 (PC4) to 3.857 (PC1), while 5 PCs were significant under ICM category with eigen values ranging from 1.061 (PC5) to 4.319 (PC1). The variance explained by PCs ranged from 12.8% (PC4) to 29.7% (PC1) under APCNF, while it ranged from 8.2% (PC5) to 33.2% (PC1) under ICM category. Thus, the PCs explained total variance of 80.9% under APCNF compared to 82.1% under ICM category. A scree plot of eigen values of PCs is described in Fig 2 which clearly indicated the significant PCs with eigen value of more than '1'.

Table 8. Eigen values and variance explained by principal components of plant parameters under APCNF and ICM categories during 2022

Principal component	APCNF		ICM	
	Eigen value	Variance (%)	Eigen value	Variance (%)
PC1	3.857	29.7	4.319	33.2
PC2	3.124	24.0	2.278	17.5
PC3	1.872	14.4	1.804	13.9
PC4	1.664	12.8	1.213	9.3
PC5	0.944		1.061	8.2
PC6	0.791		0.986	
PC7	0.311		0.485	
PC8	0.261		0.410	
PC9	0.137		0.231	
PC10	0.029		0.174	
PC11	0.007		0.034	
PC12	0.002		0.006	
PC13	0.001		0.000	
Total variance (%)		*80.9*		*82.1*

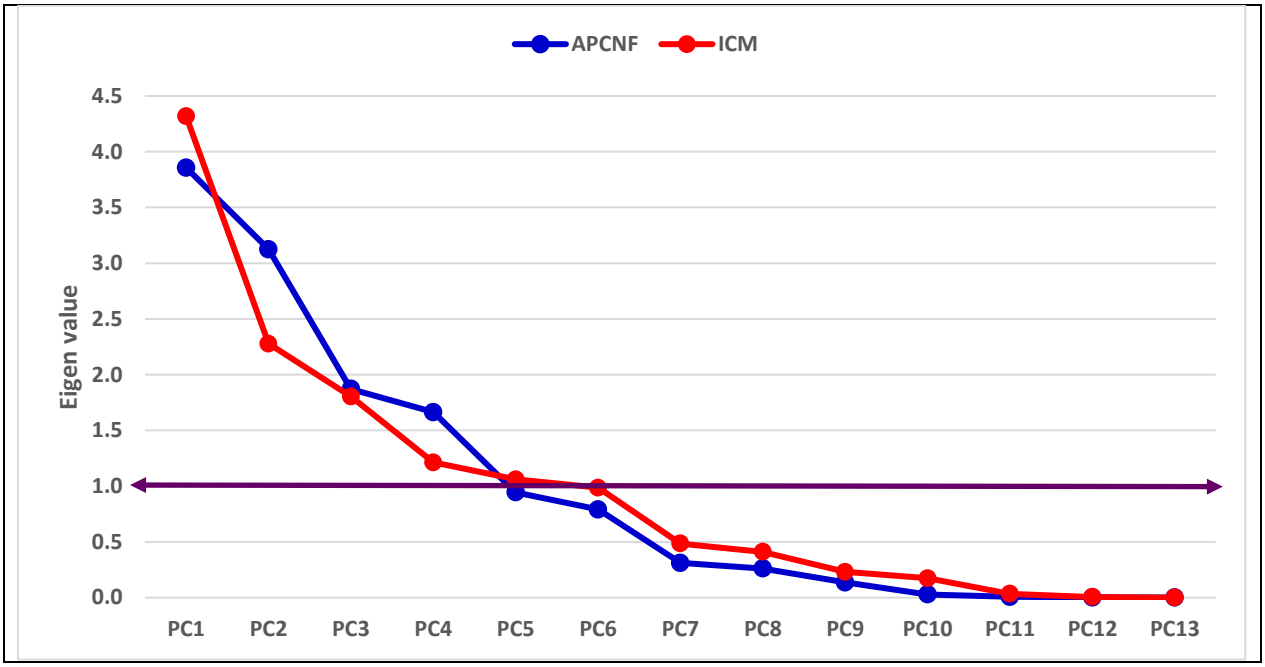


Fig 2. Scree plot of eigen values of principal components under APCNF and ICM categories

Loadings of plant parameters on principal components under APCNF and ICM categories

The loadings or weights of plant parameters on each of the 4 significant PCs under the APCNF and 5 significant PCs under the ICM categories are given in Table 9. The plant parameters which have a significant loading of either more than +0.60 or less than -0.60 on each of the significant PCs were identified. Under APCNF category, 4 parameters viz., plant height (0.894), No. of branches (0.866), No. of pods (0.796) and No. of filled pods (0.763) had significant loadings on PC1; while 3 parameters viz., shelling (-0.687), 100 kernel weight (-0.664) and 100 seed weight (0.783) had significant loadings on PC2; 2 parameters viz., root length (0.723) and haulm yield (-0.745) had significant loadings on PC3; and pod weight (0.794) had significant loading on PC4.

Under ICM category, 6 parameters viz., shelling (0.657), haulm yield (0.684), harvest index (-0.809), plant height (0.631), No. of pods (0.791) and No. of filled pods (0.775) had significant loadings on PC1; while 2 parameters viz., root length (0.703) and haulm yield (0.629) had significant loadings on PC2; 2 parameters viz., 100 pod weight (0.626) and plant height (0.615) had significant loadings on PC3; and plant population (0.617) had significant loading on PC4.

Table 9. Loadings of plant parameters on the significant principal components under APCNF and ICM categories during 2022

Plant parameter	APCNF				ICM				
	PC1	PC2	PC3	PC4	PC1	PC2	PC3	PC4	PC5
Plant population	-0.387	0.344	0.263	0.347	0.189	0.529	0.214	0.617*	-0.419
Root length (cm)	0.159	-0.110	0.723*	-0.043	0.392	0.703*	-0.059	-0.444	0.068
Shelling (%)	0.416	-0.687*	-0.366	0.109	0.657*	0.212	-0.515	0.139	0.290
100 pod weight (g)	0.156	-0.573	-0.424	-0.408	-0.117	0.098	0.626*	-0.137	-0.227
100 kernel weight (g)	0.452	-0.664*	0.302	0.127	0.404	0.214	0.466	-0.239	0.225
Pod weight (kg/ha)	0.427	-0.126	-0.363	0.794*	-0.404	0.472	0.312	0.331	0.592
Haulm yield (kg/ha)	-0.131	0.457	-0.745*	0.349	0.684*	0.629*	0.078	0.022	-0.045
Harvest index (%)	0.561	-0.514	0.310	0.544	-0.809*	-0.200	0.045	0.272	0.436
Plant height (cm)	0.894*	0.121	0.034	-0.050	0.631*	-0.066	0.615*	0.087	0.265

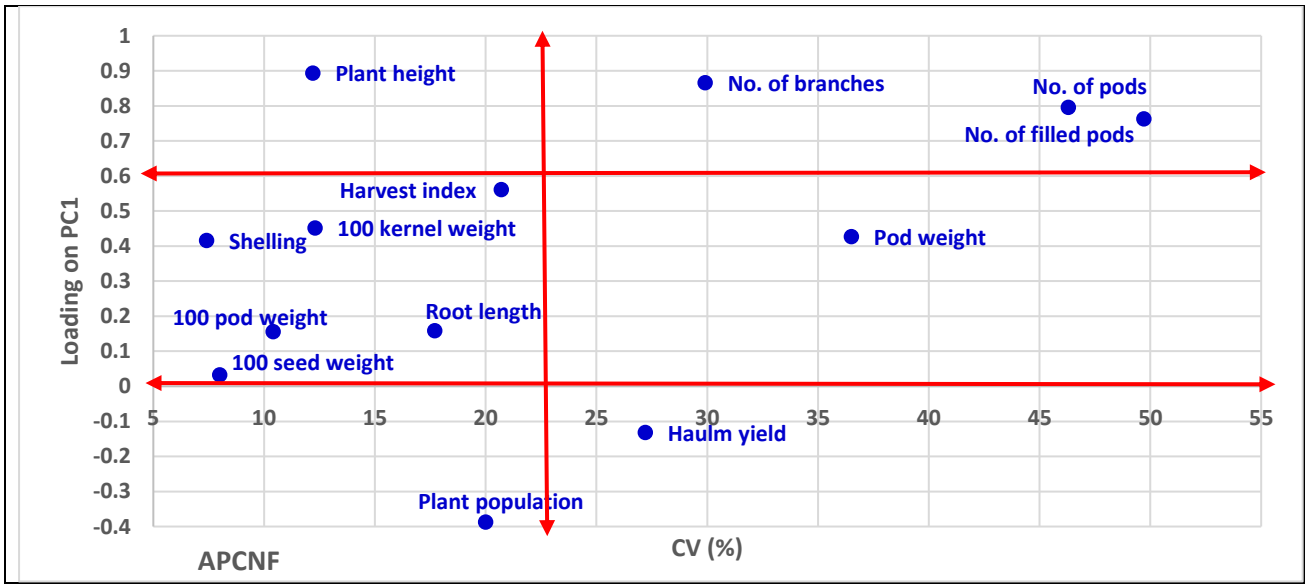
No. of branches	0.866*	0.358	0.056	-0.078	0.549	-0.489	0.319	0.450	-0.160
No. of pods	0.796*	0.486	-0.084	-0.270	0.791*	-0.482	0.062	-0.087	0.186
No. of filled pods	0.763*	0.521	-0.090	-0.241	0.775*	-0.496	0.003	-0.067	0.123
100 seed weight (g)	0.033	0.783*	0.272	0.400	0.555	0.154	-0.539	0.367	0.082

* indicates significant loading of a parameter on the corresponding principal component

Assessment of variability and loadings of plant parameters on PCs under APCNF category

An assessment has been made by considering the variability and loadings of plant parameters on each of the 4 significant PCs under APCNF category. The loadings of parameters on PC1 and PC2 and the coefficient of variation of parameters are described in Fig 3. Based on the loadings on PC1 and CV of parameters described in Fig 3 (top), (i) plant height had low CV with significant positive loading; while (ii) harvest index, shelling, 100 kernel weight, 100 pod weight, root length and 100 seed weight had low CV with non-significant positive loadings; (iii) plant population had low CV with non-significant negative loading; (iv) No. of branches, No. of pods and No. of filled pods had high CV with significant positive loading; (v) pod weight had high CV with non-significant positive loading; and (vi) haulm yield had high CV with non-significant negative loading.

Based on the loadings on PC2 and CV of parameters described in Fig 3 (bottom), (i) 100 seed weight had low CV with significant positive loading; while (ii) plant population and plant height had low CV with non-significant positive loadings; (iii) root length, harvest index and 100 pod weight had low CV with non-significant negative loading; (iv) shelling and 100 kernel weight had low CV with significant negative loading; (v) No. of branches, No. of pods, No. of filled pods and haulm yield had high CV with non-significant positive loading; and (vi) pod weight had high CV with non-significant negative loading.



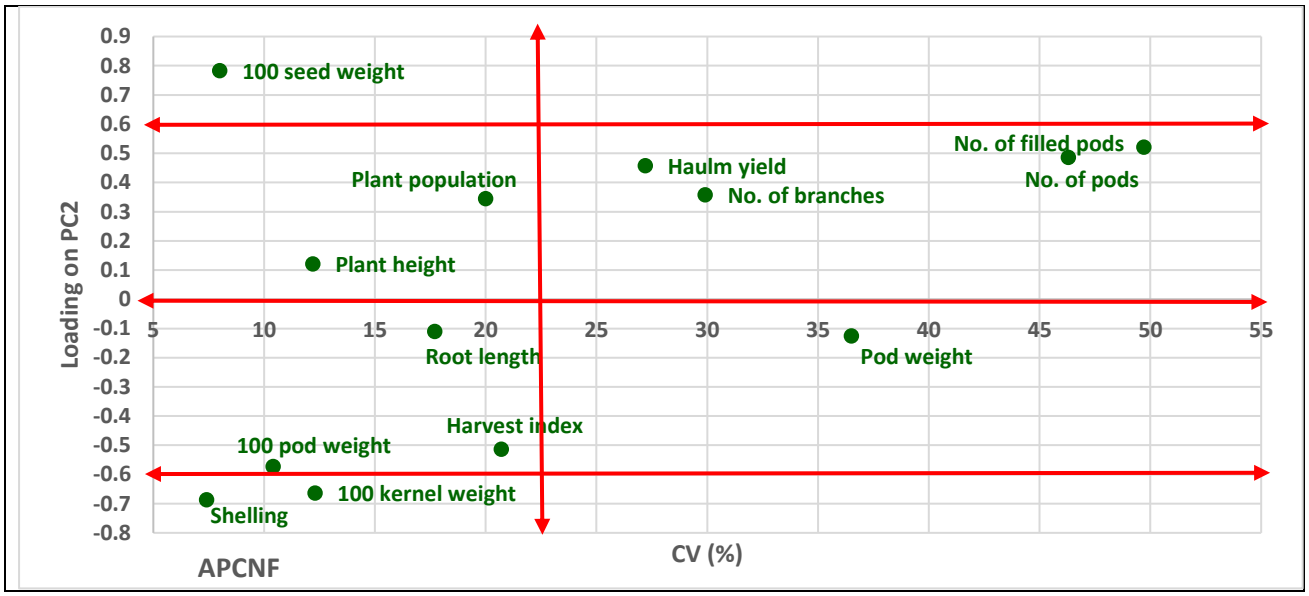


Fig 3. Variation of parameters and their loadings on principal components (PC1 and PC2) under APCNF during 2022

The loadings of parameters on PC3 and PC4 and the coefficient of variation of parameters are described in Fig 4. Based on the loadings on PC3 and CV of parameters described in Fig 4 (top), (i) root length had low CV with significant positive loading; while (ii) harvest index, 100 kernel weight, 100 seed weight, plant population and plant height had low CV with non-significant positive loadings; (iii) shelling and 100 pod weight had low CV with non-significant negative loading; (iv) No. of branches had high CV with non-significant positive loading; (v) pod weight, No. of pods and No. of filled pods had high CV with non-significant negative loading; and (vi) haulm yield had high CV with significant negative loading.

Based on the loadings on PC4 and CV of parameters described in Fig 4 (bottom), (i) harvest index, 100 seed weight, plant population, 100 kernel weight and shelling had low CV with non-significant positive loadings; while (ii) plant height, root length and 100 pod weight had low CV with non-significant negative loadings; (iii) pod weight had high CV with significant positive loading; (iv) haulm yield had high CV with non-significant positive loading; and (v) No. of branches, No. of pods and No. of filled pods had high CV with non-significant negative loadings.

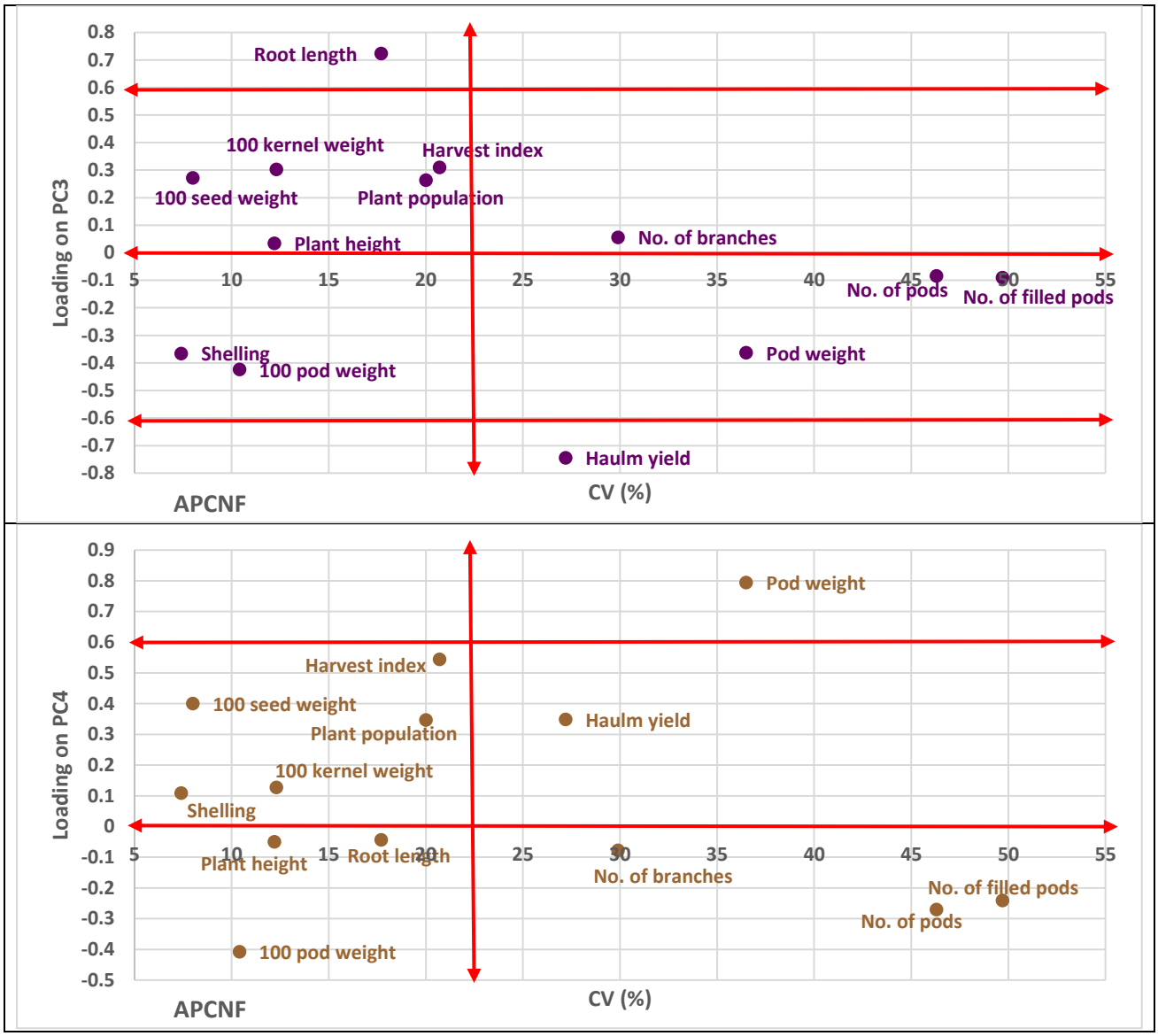


Fig 4. Variation of parameters and their loadings on principal components (PC3 and PC4) under APCNF during 2022

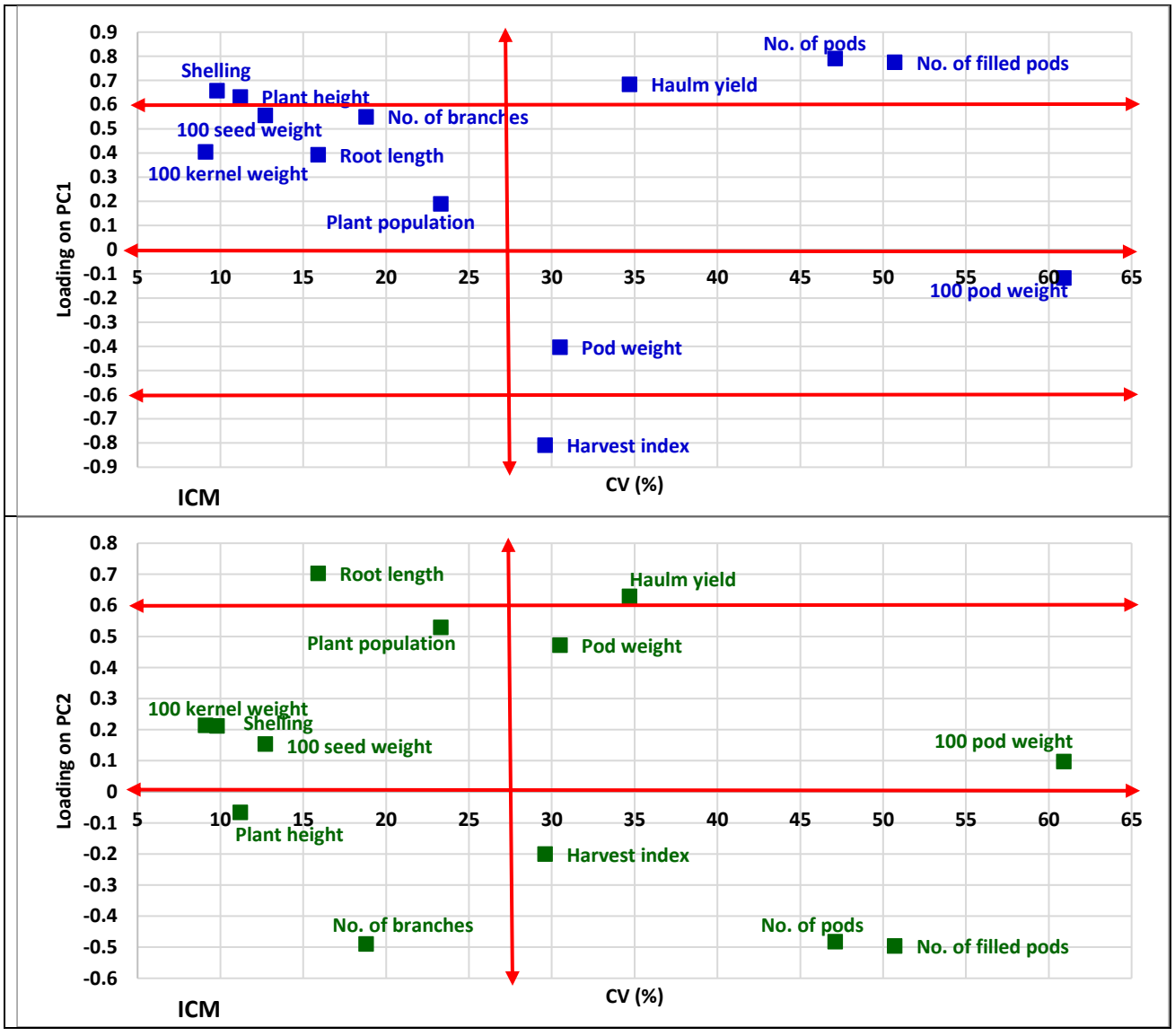
Assessment of variability and loadings of plant parameters on PCs under ICM category

An assessment has been made by considering the variability and loadings of plant parameters on each of the 5 significant PCs under the ICM category. The loadings of parameters on PC1, PC2 and PC3 and the coefficient of variation of parameters are described in Fig 5. Based on the loadings on PC1 and CV of parameters described in Fig 5 (top), (i) plant height and shelling had low CV with significant positive loadings; while (ii) No. of branches, 100 seed weight, root length, 100 kernel weight and plant population had low CV with non-significant positive loadings; (iii) Haulm yield, No. of pods and No. of unfilled pods had high CV with significant positive loadings; (iv) pod weight and 100 pod weight had high CV with non-significant negative loadings; and (v) harvest index had high CV with significant negative loading.

Based on the loadings on PC2 and CV of parameters described in Fig 5 (middle), (i) root length had low

CV with significant positive loading; while (ii) plant population, 100 kernel weight, shelling and 100 seed weight had low CV with non-significant positive loadings; (iii) plant height and No. of branches had low CV with non-significant negative loadings; (iv) haulm yield had high CV with significant positive loading; (v) pod weight and 100 pod weight had high CV with non-significant positive loadings; and (v) harvest index, No. of pods and No. of filled pods had high CV with non-significant negative loadings.

Based on the loadings on PC3 and CV of parameters described in Fig 5 (bottom), (i) plant height had low CV with significant positive loading; while (ii) plant population, No. of branches and 100 kernel weight had low CV with non-significant positive loadings; (iii) root length, shelling and 100 seed weight had low CV with non-significant negative loadings; (iv) 100 pod weight had high CV with significant positive loading; (v) pod weight, No. of pods, No. of filled pods, haulm yield and harvest index had high CV with non-significant positive loadings.



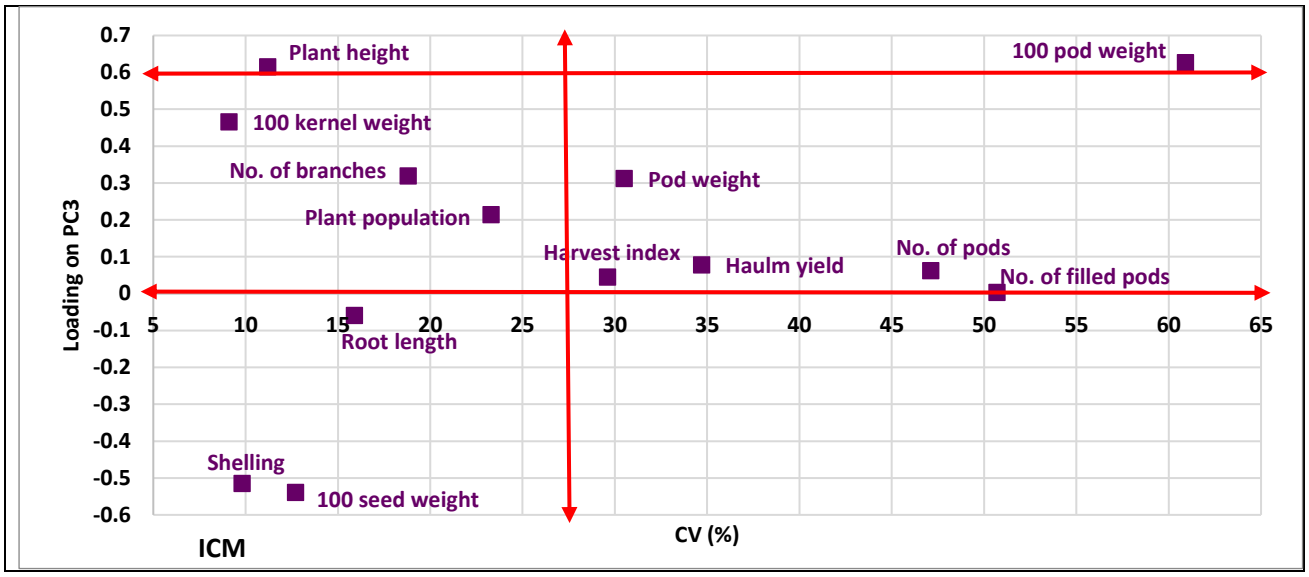


Fig 5. Variation of parameters and their loadings on principal components (PC1, PC2, and PC3) under ICM during 2022

The loadings of parameters on PC4 and PC5 and the coefficient of variation of parameters are described in Fig 6. Based on the loadings on PC4 and CV of parameters described in Fig 6 (top), (i) plant population had low CV with significant positive loading; while (ii) No. of branches, 100 seed weight, shelling and plant height had low CV with non-significant positive loadings; (iii) 100 kernel weight and root length had low CV with non-significant negative loadings; (iv) pod weight, haulm yield and harvest index had high CV with non-significant positive loadings; and (v) No. of pods, No. of filled pods and 100 pod weight had high CV with non-significant negative loadings.

Based on the loadings on PC5 and CV of parameters described in Fig 6 (bottom), (i) shelling, plant height, 100 kernel weight, root length and 100 seed weight had low CV with non-significant positive loadings; while (ii) No. of branches and plant population had low CV with non-significant negative loadings; (iii) pod weight, harvest index, No. of pods and No. of filled pods had high CV with non-significant positive loadings; and (iv) 100 pod weight and haulm yield had high CV with non-significant negative loadings.



Fig 6. Variation of parameters and their loadings on principal components (PC4 and PC5) under ICM during 2022

Ranking of treatments under APCNF and ICM based on their performance for plant parameters

Ranks were assigned to the mean values based on the performance of treatments for different plant parameters considered in two groups under APCNF and ICM. The two groups of plant parameters were viz., plant population, root length, plant height, No. of branches, shelling, No. of pods and No. of filled pods under the 1st rank sum group (RS1); and 100 pod weight, 100 kernel weight, 100 seed weight, pod yield, haulm yield and harvest index under the 2nd rank sum group (RS2). The rank sums of each treatment under APCNF and ICM are displayed in Fig 7. Under APCNF, the rank sums ranged from 21 (T12) to 67 (T14) under RS1; while it ranged from 14 (T6) to 50 (T3) under RS2 as depicted in Fig 7 (Top). T12 was superior under RS1 group, while T6 was superior under RS2 group of plant parameters. However, based on the combined rank sum of plant parameters considered under both RS1 and RS2 groups, T12 was found to be superior with lowest rank sum of 46 comprising of 21 under RS1 and 25 under RS2, while T1 was the 2nd best with rank sum of 55 comprising of 30 under RS1 and 25 under RS2. Under ICM, the rank sums ranged from 26 (T1) to 75 (T14) under RS1; while it ranged from 12 (T3) to 44 (T8)

under RS2 as depicted in Fig 7 (Bottom). T1 was superior under RS1 group, while T3 was superior under RS2 group of plant parameters. However, based on the combined rank sum of plant parameters considered under both RS1 and RS2 groups, T3 was found to be superior with lowest rank sum of 47 comprising of 35 under RS1 and 12 under RS2, while T1 was the 2nd best with rank sum of 59 comprising of 26 under RS1 and 33 under RS2.

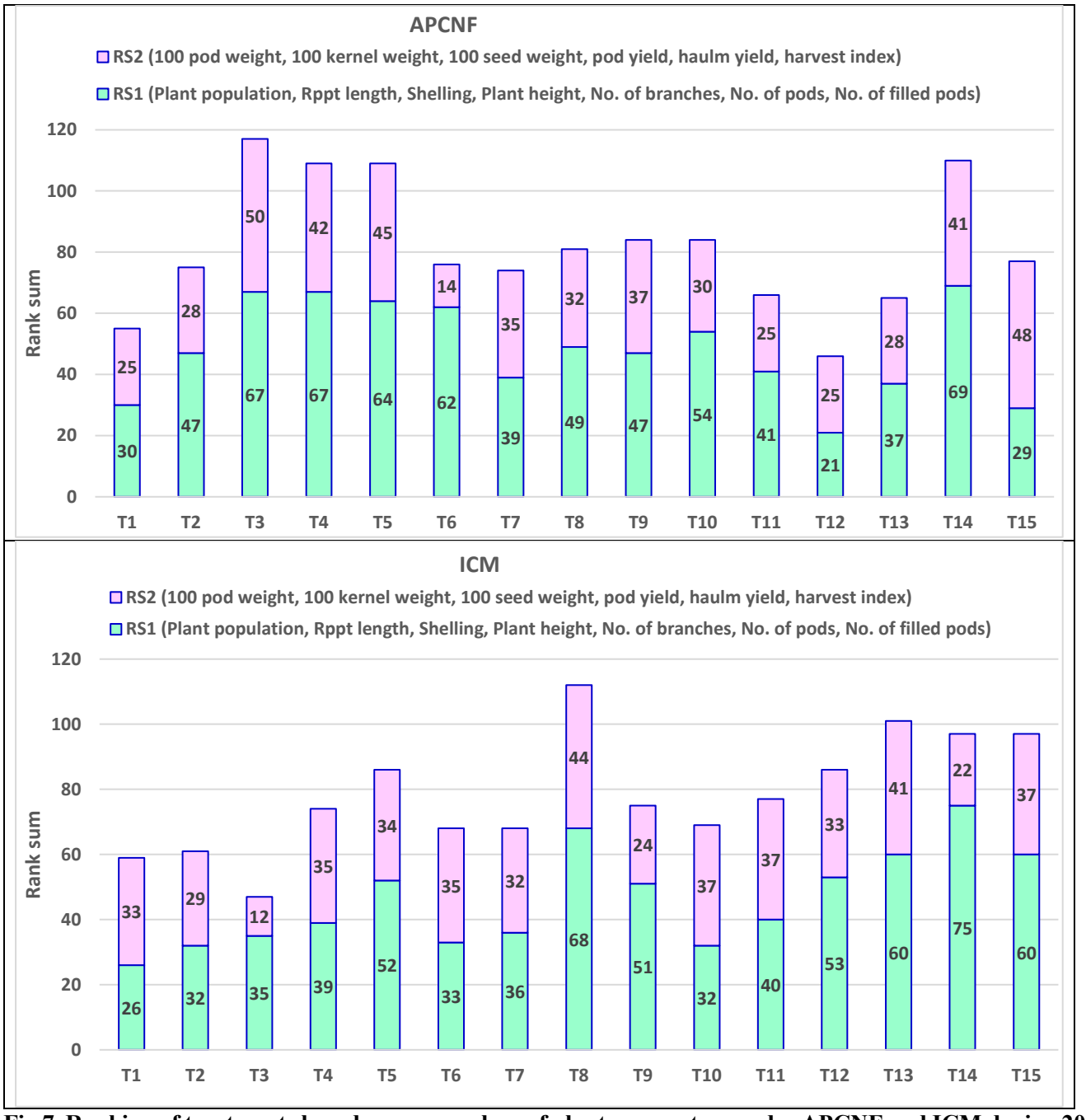
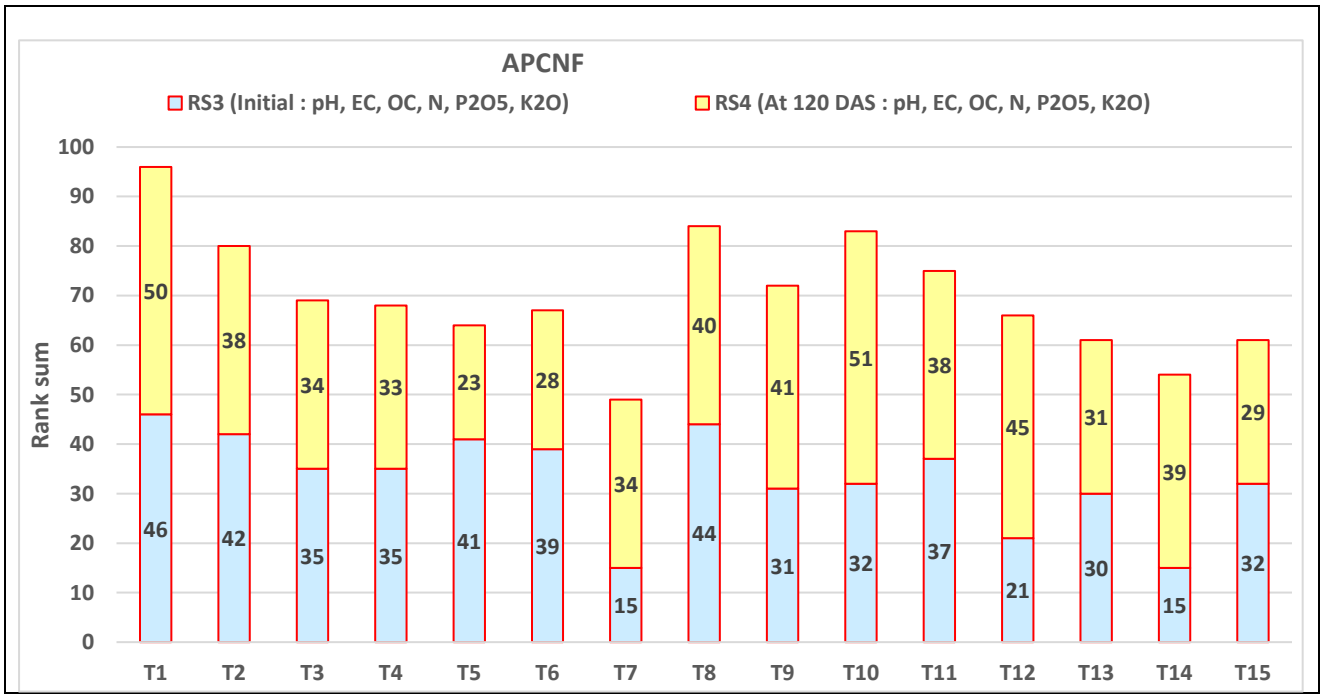


Fig 7. Ranking of treatments based on mean values of plant parameters under APCNF and ICM during 2022

Ranking of treatments under APCNF and ICM based on their performance for soil parameters

Ranks were assigned to the mean values of soil pH, electrical conductivity, organic carbon, N, P2O5 and K2O and rank sums were derived at sowing (RS3) and on 120 days after sowing (RS4) under APCNF and ICM and

are described in Fig 8. Based on Fig 8 (Top), under APCNF, the rank sum of initial soil parameters ranged from 15 (T7 and T14) to 46 (T1) under RS3, while it ranged from 23 (T5) to 51 (T10) at 120 days after sowing under RS4 group. However, based on the combined rank sum of soil parameters considered under both RS3 and RS4 groups, T7 was found to be superior with lowest rank sum of 49 comprising of 15 under RS3 and 34 under RS4, while T14 was the 2nd best with rank sum of 54 comprising of 15 under RS3 and 39 under RS4. Based on Fig 8 (Bottom), under ICM, the rank sum of initial soil parameters ranged from 27 (T12) to 50 (T7) under RS3, while it ranged from 26 (T12) to 59 (T8) at 120 days after sowing under RS4 group. However, based on the combined rank sum of soil parameters considered under both RS3 and RS4 groups, T7 was found to be superior with lowest rank sum of 53 comprising of 27 under RS3 and 26 under RS4, while T5 and T13 were the 2nd best with rank sum of 59 comprising of 29 under RS3 and 30 under RS4.



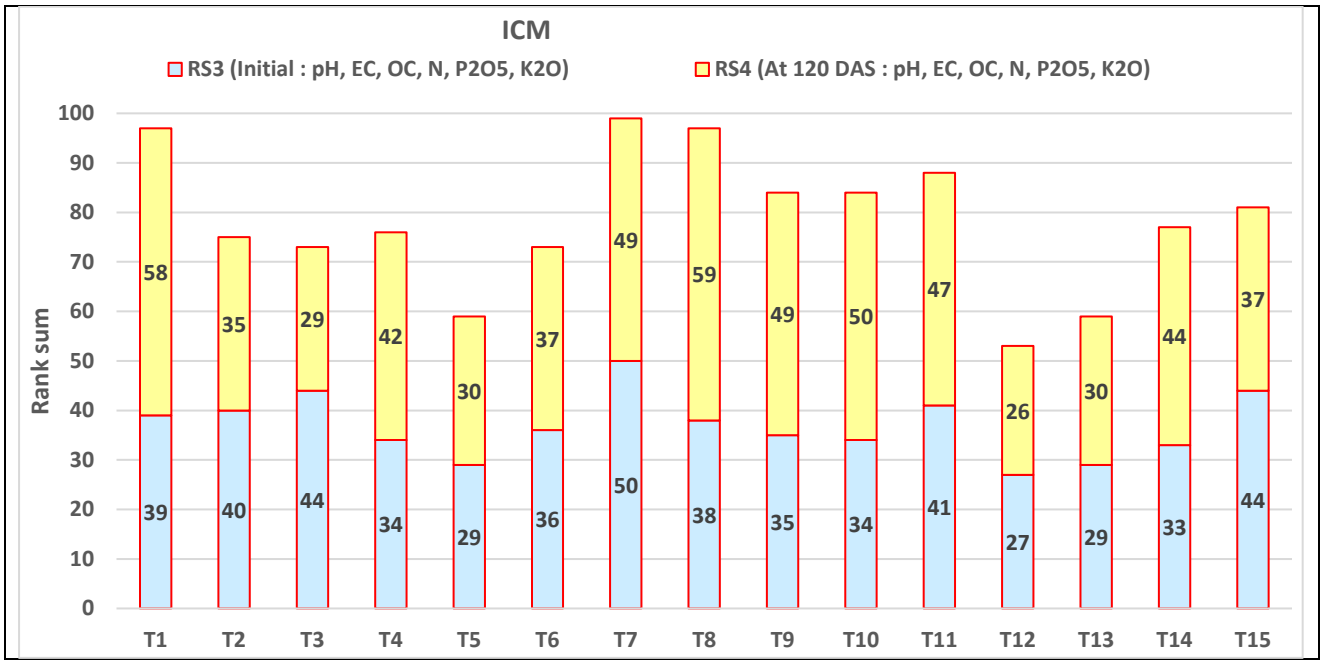


Fig 8. Ranking of treatments based on mean values of soil parameters under APCNF and ICM during 2022

Prediction of pod and haulm yield through plant parameters under APCNF and ICM categories

Regression models were calibrated to predict the pod yield (PY) and haulm yield (HY) through the significant plant parameters with loadings of more than +0.60 or less than -0.60 as identified based on the principal component analysis. Under APCNF category, 8 plant parameters which had a significant loading on the PCs viz., root length, shelling, 100 kernel weight, plant height, No. of branches, No. of pods, No. of filled pods and 100 seed weight were included in the regression model. Under the ICM category, 7 plant parameters viz., plant population, root length, shelling, harvest index, plant height, No. of pods and No. of filled pods were included in the regression model. The regression models of PY and HY, along with the estimates of coefficient of determination (R^2), prediction error (PE), mean yield and maximum yield attained under the APCNF and ICM categories are given in Table 10. The regression model gave higher R^2 of 0.65 for prediction of pod yield and 0.76 for prediction of haulm yield under the ICM category compared to 0.45 for pod yield and 0.54 for haulm yield prediction under the APCNF category. Based on the model, pod yield had a prediction error of 140.6 kg/ha under the APCNF compared to 138.8 kg/ha under the ICM category. The regression model of haulm yield gave lower prediction error of 166.0 kg/ha under the APCNF category compared to a higher prediction error of 434.6 kg/ha under the ICM category.

Under the APCNF category, shelling, 100 kernel weight, No. of pods and 100 seed weight had a positive effect, while root length, plant height, No. of branches and No. of filled pods had a negative effect on the pod yield. Similarly, shelling, No. of pods, No. of filled pods and 100 seed weight had a positive effect, while root length, 100 kernel weight, plant height and No. of branches had a negative effect on the haulm yield. Under the ICM category, plant population, root length, shelling, harvest index, plant height and No. of filled pods had a positive effect, while No. of pods had a negative effect on the pod yield. Similarly, plant population, root length, shelling, plant height and No. of filled pods had a positive effect, while harvest index and No. of pods had a negative effect on the haulm

yield.

Based on the (i) mean yield of 15 treatments, (ii) maximum yield attained by any treatment under a category and (iii) prediction error of yield based on the regression model of the respective category, estimates of sustainability yield index (SYI) were derived for attaining maximum pod yield and haulm yield of groundnut under APCNF and ICM categories. The pod yield was found to have a SYI of 32.1% for attaining maximum yield of 625 kg/ha under APCNF compared to 42.3% for attaining maximum yield of 960 kg/ha under ICM category. Similarly, the haulm yield had a SYI of 48.3% for attaining maximum yield of 880 kg/ha under APCNF compared to 44.5% for attaining maximum yield of 3100 kg/ha under ICM category.

Table 10. Regression models of pod and haulm yield through plant parameters under APCNF and ICM during 2022

Category	Regression model	R^2	PE	Mean Y	Max Y	SYI
Pod yield						
APCNF	PY = -2378.97 – 18.758 (Root length) + 20.702 (Shelling) + 10.588 (100 kernel weight) – 2.037 (Plant height) – 36.37 (No. of branches) + 2.601 (No. of pods) – 0.663 (No. of filled pods) + 10369.585 (100 seed weight)	0.45	140.6	341	625	32.1
ICM	PY = -1075.383 + 7.247 (Plant population) + 46.747 (Root length) + 1.984 (Shelling) + 2053.898* (Harvest index) + 3.966 (Plant height) – 4.747 (No. of pods) + 4.564 (No. of filled pods)	0.65	138.8	545	960	42.3
Haulm yield						
APCNF	HY = -214.233 – 58.671 (Root length) + 13.050 (Shelling) – 9.696 (100 kernel weight) – 3.874 (Plant height) – 33.713 (No. of branches) + 1.678 (No. of pods) + 1.381 (No. of filled pods) + 8390.133 (100 seed weight)	0.54	166.0	591	880	48.3
ICM	HY = -1109.419 + 41.193 (Plant population) + 203.045 (Root length) + 6.573 (Shelling) – 2797.87 (Harvest index) + 4.069 (Plant height) – 13.55 (No. of pods) + 19.433 (No. of filled pods)	0.76	434.6	1813	3100	44.5

* indicates significance at 5% level of significance

PY: Pod yield (kg/ha) HY: Haulm yield (kg/ha) SYI: Sustainability yield index (%)
R^2: Coefficient of determination PE: Prediction error (kg/ha) Mean Y: Mean yield (kg/ha)
Max Y: Maximum yield (kg/ha)

SUMMARY

Field experiment was conducted with groundnut under APCNF and ICM at Agricultural Research Station, Anantapur during 2022 under arid alfisols. Annual rainfall of 818.4 mm was received from 45 rainy days. Observations were collected on plant population, root length (cm), plant height (cm), branches, shelling (%), No. of pods, No. of filled pods, 100 pod weight (g), 100 kernel weight (g), 100 seed weight (g), pod weight (kg/ha), haulm yield (kg/ha) and harvest index (%). Under APCNF, plant population ranged from 10-25 with mean of 18.8 (CV of 20.0%), while root length ranged from 4.1-7.6 cm with mean of 5.9 cm (17.7%). Plant height ranged from 94.6-140.3 cm with mean of 117.4 cm (12.2%), while shelling ranged from 56-78% with mean of 66.9% (7.4%). 100 pod weight ranged from 64-94 g with mean of 79.7 g (10.4%), while 100 kernel weight ranged from 28-44 g with mean of 36.9 g (12.3%). Pod weight ranged from 195-625 kg/ha with mean of 340.7 kg/ha (36.5%), while

haulm yield ranged from 338-880 kg/ha with mean of 590.9 kg/ha (27.2%). Branches ranged from 2.6-7.6 with mean of 4.7 (29.9%), while No. of pods ranged from 22.6-107.8 with mean of 58.5 (46.3%). No. of filled pods ranged from 18.2-84.8 with mean of 46.7 (49.7%), while 100 seed weight ranged from 0.12-0.14 g with mean of 0.13 g (8.0%). Harvest index ranged from 0.24-0.47 with mean of 0.36 (20.7%). Under ICM, plant population ranged from 16-36 with mean of 24.0 (23.3%), while root length ranged from 6.1-9.4 cm with mean of 7.6 cm (15.9%). Plant height ranged from 108.6-168.1 cm with mean of 141.5 cm (11.2%), while shelling ranged from 50-72% with mean of 64.1% (9.8%). 100 pod weight ranged from 9-94 g with mean of 58.0 g (60.9%), while 100 kernel weight ranged from 28-38 g with mean of 33.9 g (9.1%). Pod weight ranged from 340-960 kg/ha with mean of 545.5 kg/ha (30.5%), while haulm yield ranged from 1000-3100 kg/ha with mean of 1813.3 kg/ha (34.7%). Branches ranged from 7.4-14.6 with mean of 11.6 (18.8%), while No. of pods ranged from 10.8-125.4 with mean of 69.5 (47.1%). No. of filled pods ranged from 8.4-95.8 with mean of 52.2 (50.7%), while 100 seed weight ranged from 0.10-0.14 g with mean of 0.13 g (12.7%). Harvest index ranged from 0.14-0.34 with mean of 0.24 (29.6%).

Under APCNF, initial pH ranged from 7.1-7.9 with mean of 7.6 (3.6%), while pH on 120 DAS ranged from 6.8-7.3 with mean of 7.1 (1.9%). Initial EC ranged from 0.08-0.14 ds/m with mean of 0.11 ds/m (13.3%), while EC on 120 DAS ranged from 0.15-0.22 ds/m with mean of 0.19 ds/m (10.3%). Initial OC ranged from 0.27-0.38% with mean of 0.33% (11.2%), while OC on 120 DAS ranged from 0.15-0.46% with mean of 0.30% (29.7%). Initial N ranged from 174.9-199.0 kg/ha with mean of 187.9 kg/ha (4.6%), while N on 120 DAS ranged from 117.0-189.2 kg/ha with mean of 157.5 kg/ha (14.8%). Initial P_2O_5 ranged from 27.9-46.9 kg/ha with mean of 40.2 kg/ha (13.1%), while P_2O_5 on 120 DAS ranged from 21.2-72.4 kg/ha with mean of 44.9 kg/ha (30.3%). Initial K_2O ranged from 176.0-571.6 kg/ha with mean of 321.6 kg/ha (33.5%), while K_2O on 120 DAS ranged from 290.7-602.1 kg/ha with mean of 439.5 kg/ha (17.9%). Under ICM, initial pH ranged from 6.8-7.9 with mean of 7.3 (4.5%), while pH on 120 DAS ranged from 7.0-7.7 with mean of 7.2 (2.8%). Initial EC ranged from 0.10-0.18 ds/m with mean of 0.13 ds/m (16.0%), while EC on 120 DAS ranged from 0.02-0.28 ds/m with mean of 0.17 ds/m (32.8%). Initial OC ranged from 0.25-0.40% with mean of 0.33% (14.6%), while OC on 120 DAS ranged from 0.08-0.49% with mean of 0.28% (41.5%). Initial N ranged from 181.4-298.5 kg/ha with mean of 256.6 kg/ha (16.4%), while N on 120 DAS ranged from 78.7-174.8 kg/ha with mean of 126.2 kg/ha (21.8%). Initial P_2O_5 ranged from 36.8-51.8 kg/ha with mean of 44.9 kg/ha (10.4%), while P_2O_5 on 120 DAS ranged from 41.3-72.0 kg/ha with mean of 55.8 kg/ha (17.2%). Initial K_2O ranged from 312.2-414.8 kg/ha with mean of 365.7 kg/ha (8.8%), while K_2O on 120 DAS ranged from 138.1-462.9 kg/ha with mean of 264.1 kg/ha (41.6%).

Significant differences existed between APCNF and ICM for plant population, root length, pod weight, haulm yield, harvest index, plant height and branches, 100 pod weight and 100 kernel weight. Plant population, root length, pod weight, haulm yield, plant height and branches were significantly higher under ICM, while 100 pod weight, 100 kernel weight and harvest index were significantly higher under APCNF. Ranks were assigned to the mean values of treatments for different plant parameters under APCNF and ICM. The two groups of plant parameters were viz., plant population, root length, plant height, No. of branches, shelling, No. of pods and No. of filled pods under the 1st rank sum group (RS1); and 100 pod weight, 100 kernel weight, 100 seed weight, pod yield,

haulm yield and harvest index under the 2nd rank sum group (RS2). Under APCNF, T12 was superior under RS1 group, while T6 was superior under RS2 group. Based on the combined rank sum, T12 was superior. Under ICM, T1 was superior under RS1 group, while T3 was superior under RS2 group. Based on the combined rank sum, T3 was superior. Under both APCNF and ICM, the rank sum of soil parameters indicated that T7 was superior.

Under APCNF, significant positive correlation existed between (i) shelling and 100 pod weight (0.625); (ii) 100 kernel weight and harvest index (0.732); (iii) pod weight and harvest index (0.641); (iv) plant height with branches (0.790), pods (0.745), filled pods (0.723); (v) branches with pods (0.830), filled pods (0.787); (vi) No. of pods with filled pods (0.989). Significant negative correlation existed between (i) shelling and 100 seed weight (-0.518); (ii) 100 pod weight and 100 seed weight (-0.568); (iii) 100 kernel weight and haulm yield (-0.540). Under ICM, significant positive correlation existed between (i) root length and haulm yield (0.636); (ii) shelling and 100 seed weight (0.707); (iii) pod weight and harvest index (0.595); (iv) plant height with branches (0.588), pods (0.572); (v) branches with No. of pods (0.531), filled pods (0.544); (vi) No. of pods and filled pods (0.985); while significant negative correlation existed between haulm yield and harvest index (-0.712).

Based on PC analysis, 4 PCs were significant under APCNF, compared to 5 under ICM. Variance explained by PCs ranged from 12.8% (PC4) to 29.7% (PC1) under APCNF compared to 8.2% (PC5) to 33.2% (PC1) under ICM. Thus, total variance of 80.9% and 82.1% was explained under APCNF and ICM respectively. Under APCNF, plant height (0.894), branches (0.866), pods (0.796) and filled pods (0.763) had significant loadings on PC1; compared to shelling (-0.687), 100 kernel weight (-0.664) and 100 seed weight (0.783) on PC2; root length (0.723) and haulm yield (-0.745) on PC3; pod weight (0.794) on PC4. Under ICM, shelling (0.657), haulm yield (0.684), harvest index (-0.809), plant height (0.631), No. of pods (0.791) and filled pods (0.775) had significant loadings on PC1; compared to root length (0.703) and haulm yield (0.629) on PC2; 100 pod weight (0.626) and plant height (0.615) on PC3; plant population (0.617) on PC4.

Under APCNF, considering loadings on PC1 and CV of parameters, (i) plant height had low CV with significant positive loading; while (ii) harvest index, shelling, 100 kernel weight, 100 pod weight, root length and 100 seed weight had low CV with non-significant positive loadings; (iii) plant population had low CV with non-significant negative loading; (iv) branches, pods and filled pods had high CV with significant positive loading; (v) pod weight had high CV with non-significant positive loading; (vi) haulm yield had high CV with non-significant negative loading. Considering loadings on PC2 and CV of parameters (i) 100 seed weight had low CV with significant positive loading; while (ii) plant population and plant height had low CV with non-significant positive loadings; (iii) root length, harvest index and 100 pod weight had low CV with non-significant negative loading; (iv) shelling and 100 kernel weight had low CV with significant negative loading; (v) branches, pods, filled pods and haulm yield had high CV with non-significant positive loading; (vi) pod weight had high CV with non-significant negative loading.

Considering loadings on PC3 and CV of parameters, (i) root length had low CV with significant positive loading; while (ii) harvest index, 100 kernel weight, 100 seed weight, plant population and plant height had low CV with non-significant positive loadings; (iii) shelling and 100 pod weight had low CV with non-significant negative

loading; (iv) branches had high CV with non-significant positive loading; (v) pod weight, No. of pods and filled pods had high CV with non-significant negative loading; (vi) haulm yield had high CV with significant negative loading. Considering loadings on PC4 and CV of parameters (i) harvest index, 100 seed weight, plant population, 100 kernel weight and shelling had low CV with non-significant positive loadings; while (ii) plant height, root length and 100 pod weight had low CV with non-significant negative loadings; (iii) pod weight had high CV with significant positive loading; (iv) haulm yield had high CV with non-significant positive loading; (v) branches, pods and filled pods had high CV with non-significant negative loadings.

Under ICM, considering loadings on PC1 and CV of parameters, (i) plant height and shelling had low CV with significant positive loadings; while (ii) branches, 100 seed weight, root length, 100 kernel weight and plant population had low CV with non-significant positive loadings; (iii) Haulm yield, No. of pods and filled pods had high CV with significant positive loadings; (iv) pod weight and 100 pod weight had high CV with non-significant negative loadings; (v) harvest index had high CV with significant negative loading. Considering loadings on PC2 and CV of parameters, (i) root length had low CV with significant positive loading; while (ii) plant population, 100 kernel weight, shelling and 100 seed weight had low CV with non-significant positive loadings; (iii) plant height and branches had low CV with non-significant negative loadings; (iv) haulm yield had high CV with significant positive loading; (v) pod weight and 100 pod weight had high CV with non-significant positive loadings; (v) harvest index, No. of pods and filled pods had high CV with non-significant negative loadings.

Considering loadings on PC3 and CV of parameters, (i) plant height had low CV with significant positive loading; while (ii) plant population, branches and 100 kernel weight had low CV with non-significant positive loadings; (iii) root length, shelling and 100 seed weight had low CV with non-significant negative loadings; (iv) 100 pod weight had high CV with significant positive loading; (v) pod weight, No. of pods and filled pods, haulm yield and harvest index had high CV with non-significant positive loadings. Considering loadings on PC4 and CV of parameters, (i) plant population had low CV with significant positive loading; while (ii) branches, 100 seed weight, shelling and plant height had low CV with non-significant positive loadings; (iii) 100 kernel weight and root length had low CV with non-significant negative loadings; (iv) pod weight, haulm yield and harvest index had high CV with non-significant positive loadings; (v) No. of pods, filled pods and 100 pod weight had high CV with non-significant negative loadings. Considering loadings on PC5 and CV of parameters, (i) shelling, plant height, 100 kernel weight, root length and 100 seed weight had low CV with non-significant positive loadings; while (ii) branches and plant population had low CV with non-significant negative loadings; (iii) pod weight, harvest index, No. of pods and filled pods had high CV with non-significant positive loadings; (iv) 100 pod weight and haulm yield had high CV with non-significant negative loadings.

Regression models were calibrated to predict pod and haulm yields through significant parameters identified based on PC analysis. APCNF model included root length, shelling, 100 kernel weight, plant height, branches, pods, filled pods and 100 seed weight, while ICM model included plant population, root length, shelling, harvest index, plant height, No. of pods and filled pods. ICM model gave R^2 of 0.65 for pod yield and 0.76 for haulm yield compared to 0.45 and 0.54 under APCNF respectively. Under APCNF, shelling, 100 kernel weight,

No. of pods and 100 seed weight had positive effect, while root length, plant height, branches and filled pods had negative effect on pod yield. Similarly, shelling, No. of pods, filled pods and 100 seed weight had positive effect, while root length, 100 kernel weight, plant height and branches had negative effect on haulm yield. Under ICM, plant population, root length, shelling, harvest index, plant height and filled pods had positive effect, while No. of pods had negative effect on pod yield. Similarly, plant population, root length, shelling, plant height and filled pods had positive effect, while harvest index and No. of pods had negative effect on haulm yield.

Based on the (i) mean yield of 15 treatments, (ii) maximum yield attained by any treatment under a category and (iii) prediction error of yield based on the regression model of the respective category, pod yield was found to have a SYI of 32.1% for attaining maximum yield of 625 kg/ha under APCNF compared to 42.3% for attaining maximum yield of 960 kg/ha under ICM. Similarly, haulm yield had a SYI of 48.3% for attaining maximum yield of 880 kg/ha under APCNF compared to 44.5% for attaining maximum yield of 3100 kg/ha under ICM category. The findings based on the study are applicable to the similar soil and agro-climatic conditions in any region.

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Data Availability: The datasets used and or analysed during the current study are available from the corresponding author on reasonable request.

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Clinical trial number: not applicable.

Declarations

Ethical Approval

This study did not involve human participants or animals; therefore, formal ethical approval was not required.

Consent to Participate

No human participants were involved in this study; therefore, consent to participate was not applicable.

Consent for Publication

Not applicable. This manuscript does not contain data from any individual person in any form.

Competing Interest

The authors declare that they have no competing interests.

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