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Research Paper

Productivity, leaf quality and nutrient-use efficiency of FCV tobacco (*Nicotiana tabacum*) genotypes to levels of N and K application under irrigated Alfisols of Andhra Pradesh

S.V. KRISHNA REDDY[1], S. KASTURI KRISHNA[2], D. DAMODAR REDDY[3], C. CHANDRASEKHARA RAO[4] AND K. NAGESWARA RAO[5]

ICAR-Central Tobacco Research Institute Research Station, Jeelugumilli, Andhra Pradesh 534 456

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ABSTRACT

A field experiment was conducted for 3 consecutive seasons (2010–2013) at Jeelugumilli, Andhra Pradesh to assess the yield potential, leaf quality and nutrient-use efficiency of flue-cured Virginia (FCV) tobacco (*Nicotiana tabacum* L.) genotypes grown in irrigated Alfisols in relation to N and K management. Results showed that FCV tobacco cv. 'Kanchan' and hybrid 'CH-1' were on par with regard to yield and grade index. Graded rates of N and K application caused progressive and significant increase in green leaf, cured leaf and grade index. Recommended dose of fertilizers (RDF) produced significantly higher cured leaf yield by 13.0, 45.8 and 193.8% and grade index by 14.1, 53.7 and 224.4%, when compared to 80, 40 and 0 kg N/ha respectively. RDF produced significantly higher cured leaf yield by 2.69, 8.52 and 26.5% and grade index by 5.80, 16.8 and 43.1% when compared to 66.4, 33.2 and 0 kg K/ha respectively. The leaf chemical quality parameters viz. nicotine, reducing sugars, reducing sugars/nicotine ratio and chlorides showed changes in response to N and K rates and were within the acceptable limits. The mean total N uptake ranged from 12.9 to 73.5 and mean K uptake ranged from 30.6 to 81.5 kg/ha. Total N and K uptake was marginally higher in cv. 'Kanchan' (3.63%) and 'CH-1' (4.14%), respectively. In the total 52.2 kg/ha of N uptake, proportion of N accumulation in leaf, stem and root was 54, 25.4 and 20.7% respectively. In the total 61.5 kg/ha K uptake, proportion of K accumulated in leaf, stem and root was 73.4, 17.6 and 9.0% respectively. Agronomic-use efficiency, physiological efficiency, internal efficiency, partial factor productivity and recovery efficiency were higher at lower levels of N and K and decreased with increase in their levels. Nutrient harvest index (translocation index) for N and K almost remained same with increase in N and K level. Both cv. 'Kanchan' and hybrid 'CH-1' performed on par and would require 120–26.2–99.6kg N-P-K/ha when grown after sunnhemp *in situ* green manure for getting optimum productivity, better grade index with acceptable chemical quality parameters, optimum nutrient-uptake and nutrient use-efficiencies under irrigated Alfisols of Andhra Pradesh.

Key words : FCV tobacco, Leaf quality, Nitrogen, Nitrogen-use efficiency, Productivity, Potassium, Potassium-use efficiency

Export quality semi-flavourful to flavourful Flue-Cured Virginia (FCV) tobacco is being cultivated in an area of 28,850 ha, producing about 64,360 tonnes of leaf in sands, sandy loams and loamy sands (Alfisols) of irrigated area comprising of East Godavari, West Godavari districts of Andhra Pradesh and Khammam district of Telangana. The total dry matter, economic yield, quality and quantity of nutrient uptake by a tobacco crop varies considerably among tobacco types, spacing, fertilization, residual level of soil nutrients, rainfall and other environmental factors (Collins and Hawks, 1993). In irrigated Alfisol conditions, cv. 'Kanchan' and hybrid 'CH-1'having 24–26 curable leaves are being grown on larger area due to their higher yield potential and superior leaf quality characters. Nitrogen is the most important element and has more pronounced effect on the growth, development and quality of flue-cured tobacco than other essential elements. However, excess quantity of N lowers quality and the yield of tobacco (Collins, 2003) and also reported to increase ni-

[1]**Corresponding author's Email:** 65svkreddy@gmail.com
[1]Principal Scientist (Agronomy), [2]Principal Scientist (Agronomy) and Head, Division of Crop Production, [3]Director, [4]Principal Scientist (Soil Science) and Head, Division of Crop Chemistry and Soil Science; [5]Principal Scientist (Plant Physiology, Retd.), ICAR-Central Tobacco Research institute, Rajamahendravaram, East Godavari, Andhra Pradesh 533 105

trate concentration of drinking water (Prasad *et al*., 2016). Potassium is known to improve the colour, texture, body, elasticity, fire holding capacity and combustibility of cured tobacco leaf besides its role in influencing the water relations and photosynthesis of green plants. Study of N and K-use efficiencies for FCV tobacco grown in irrigated Alfisols will help in determining the optimum use of these nutrients, thus avoiding the excessive application and thereby enhancing nutrient-use efficiencies. Knowing the nutrient uptake by the crop at different levels of N and K will help in determining the actual requirement of the nutrients by the crop and thereby producing a quality crop by maintaining the soil productivity for posterity.Very little work has been done on the nutrient uptake and nutrient-use efficiencies of FCV tobacco cv. 'Kanchan' and hybrid 'CH-1' with different levels of N and K. Keeping the above points in view, the field investigation was carried out to workout suitable N and K management practices for FCV tobacco cv. 'Kanchan' and hybrid 'CH-1' for realizing optimum productivity and superior leaf quality in irrigated Alfisols.

MATERIALS AND METHODS

A field experiment was conducted for 3 consecutive seasons in fixed plots during winter season (*rabi*) 2010–2013 at the research farm of ICAR-Central Tobacco Research Institute, Research Station, Jeelugumilli (17°11 30 N and 81°07 50 E at 150 m above mean sea-level), West Godavari district, Andhra Pradesh under semi-arid tropical climate. The soil was sandy loam (0–22.5 cm) and deeper layers (22.5–45.0 cm) were sandy clay classified Typic Haplustalfs with slightly acidic *p*H (1:2.5) 6.35, low electrical conductivity (1:2.5) 0.22 dS/m, chlorides 30 mg/kg, low in organic carbon (0.21%) and available N (115 kg/ha), high in available P (24 kg/ha) and medium in available K (230 kg/ha).

The treatments comprising 2 widely grown cultivars (cv. 'Kanchan' and hybrid 'CH-1') and combinations of 5 levels each of N (0, 40, 80, 120 and 160 kg N/ha) and K (0, 33.2, 66.4, 99.6 and 132.8 kg K/ha) were evaluated with 3 replications in a factorial RBD. The recommended dose of fertilizer (RDF) is 120–26.2–99.6 kg N-P-K/ha. Sunnhemp [*Crotalaria juncea* (L.) Rotar and Joy] seed @ 50 kg/ha was sown in the first week of June and *in situ* incorporation was done before flowering i.e. in first week of August. The incorporated dry matter of sunnhemp was about 4.0 t/ha with N content of 2.15% (on oven dry weight basis) in 3 years. The gross plot size was 6 m × 6 m (60 plants) and the net plot size was 4 m × 4.8 m (32 plants) with spacing of 100 cm × 60 cm. About 60-days-old tobacco seedlings of cv 'Kanchan' and hybrid 'CH-1' were planted on 10, 6 and 11 October during first, second and third seasons respectively. Nitrogen and potassium were applied in 3 splits in 1:2:1 proportion at 7–10, 25–30 and 45–50 days after planting (DAP) as per the treatment. Phosphorus was applied @ 26.2 kg P/ha as basal dose. In basal dose, first split of N and full dose of P in the form of di-ammonium phosphate and 25% K in the form of potassium sulphate were applied 10 days after planting. In basal dose, calcium ammonium nitrate (CAN) was applied to supplement higher levels of N (above 26.2 kg P/ha through di-ammonium phosphate level i.e. above 23.4 kg N/ha). Single super phosphate (SSP) was applied wherever N was not included in the treatments. In top dressing, second split (50%) of N and K were given through CAN and sulphate of potash at 25–30 DAP. Remaining 25% each of N and K as CAN and potassium sulphate was applied at 45–50 DAP. All the fertilizers were applied in dollop method at 10 cm away and at a depth of 10 cm on either side of the plant by making holes by either sticks (*Gasika*) or spades.

The crop was raised with assured irrigation using furrow method and recommended package of practices except the inputs applied as treatments. The crop was topped at 24 leaves at bud stage. Decanol (n-deconol, a fatty alcohol based suckericide) 4% was applied @ 10-15 ml/plant immediately after topping for preventing the sucker growth. The first priming was done 80 DAP. Mature leaves were harvested by priming and flue cured in the barn. The total rainfall during the crop season was 208.8 mm (6 rainy days) in first, 380.2 (25 rainy days) in second and 80.8 mm (7 rainy days) in third season. Mean maximum and minimum temperatures were 36 and 15.0°C in the first, 36.1 and 15.4°C in the second and 36.8 and 14.9°C in the third season respectively.

The data on tobacco green leaf and cured leaf were recorded and grade index was calculated. The cured leaf samples of tobacco collected from primings (P), lugs and cutters (X), leaf (L) and tips (T) positions were processed and analysed for lamina chemical quality characters (reducing sugars, nicotine and chlorides) as per the standard procedures and reducing sugars/nicotine was calculated. N, P and K contents were determined in leaf, stem and root of all the treatments. Nutrient uptake (N, P and K) was estimated by multiplying the nutrient content with respective dry weights. Total nutrient uptake was obtained by summing the individual uptakes of leaf, stem and root. Nutrient-use efficiencies were calculated.

Agronomic-use efficiency (AUE) is defined as the economic yield (kg) in nutrient (N/K) treated plot minus leaf yield (kg) in control (N/K=0) plot per unit amount of nutrient applied (kg) and is a measure of additional yield (kg) produced for each kg of nutrient applied over the control. Physiological efficiency (PE) is the leaf yield in nutrient

(N/K) treated plot (kg) minus leaf yield in control (N/K=0) plot (kg) divided by total nutrient uptake in N/K treated plot (kg) minus total nutrient uptake in control (N/K=0) plot (kg) and explains the additional yield for each additional kg of nutrient uptake over control. Internal efficiency (IE) is economic yield (kg) per total nutrient uptake (kg) and measures the yield produced per kg nutrient taken up from both fertilizer and indigenous (soil) nutrient sources i.e. total nutrient uptake. Partial factor productivity (PFP) or input-use efficiency is the leaf yield (kg) per unit amount of nutrient applied (kg) and measures the yield produced for each kg of nutrient applied. Recovery efficiency (RE) is the percentage of nutrient uptake in nutrient treated plot (kg) minus nutrient uptake in control (N/K=0) plot (kg) divided by the amount of N/K applied (kg) and gives how much percentage of nutrient applied was recovered and taken up by the crop at the end of the cropping season. Nutrient harvest index (NHI) is proportion of leaf nutrient to total shoot nutrient (Surekha *et al*., 2008). The data were statistically analysed and results of pooled analysis were presented.

RESULTS AND DISCUSSION

Yield characters

The FCV tobacco cv. 'Kanchan' and hybrid 'CH-1' were on par with regard to green leaf yield, cured leaf yield and grade index, while cv. 'Kanchan' recorded higher green leaf/cured leaf than 'CH-1' and 'CH-1' recorded higher grade index/cured leaf (%) indicating proportionately better grade index in hybrid 'CH-1' (Table 1). These variations might be due to the inherent genetic differences among the varieties.

Mean green leaf yield, cured leaf yield and grade index increased progressively and significantly with application of graded levels of nitrogen from 0-160 kg N/ha. The green leaf yield, cured leaf yield and grade index at recommended dose of fertilizer was significantly higher than the lower levels of N. Green leaf yield at RDF was significantly higher by 1.42 (14.7%), 3.7 (49.9%) and 7.54 t/ha (211%) than that at 80, 40 and 0 kg N/ha, respectively. Cured leaf yield at RDF was significantly higher by 0.22 (13.0%), 0.6 (45.8%) and 1.26 t/ha (193.8%) than that at 80, 40 and 0 kg N/ha, respectively. Grade index at RDF was significantly higher by 0.18 (14.1%), 0.51 (53.7%) and 1.01 t/ha (224.4%) than that of 80, 40 and 0 kg N/ha respectively. Green leaf yield, cured leaf yield and grade index at 160 kg N/ha was higher by 0.78 (7.02%), 0.13 (6.81%) and 0.06 t/ha (4.11%) as compared to recommended dose of nitrogen. This is because, higher rates of application have a better edge for growth due to increased proportion of both the nutrient retention in soil and its uptake by plant.

It was observed that the first N increment from 0 to 40 kg resulted in 0.66 and 0.50 t/ha, while the second N increment from 40 to 80 kg N produced 0.38 and 0.33 t/ha, the third N increment from 80 to 120 kg N produced 0.22 and 0.18 t/ha and the fourth N increment from 120 to 160 kg produced only 0.13 and 0.6 t/ha increase in cured leaf and grade index respectively. This is due to law of diminishing returns i.e. the yield increases less than proportionate with each successive addition of input and the total return increases but at a diminishing rate. This also follows the Mitscherlich's equation, which states that the increase in growth with each successive addition of element in question was progressively smaller. Kumar *et al.* (2013) also observed that the response for cured leaf yield with respect to different levels of either nitrogen or potassium was linear and grade index was proportionately more at lower levels of N than at higher levels. These results are also in conformity with the reports of Kasturi Krishna *et al*. (2009, 2016) and Krishna Reddy *et al*. (2006). Application of 120 kg N/ha being on a par with 80 and 160 kg recorded higher green leaf/cured leaf and grade index/cured leaf (%) as compared to 0 and 40 kg N/ha. This indicated a clear crop response to N supply in Alfisols characterized by low native N and K reserves and low CEC coupled with high vulnerability to leaching losses (Kasturi Krishna *et al.* 2016).

Green leaf yield, cured leaf yield and grade index increased progressively and significantly with application of graded levels of potassium from 0–99.6 kg K/ha only and the differences between 99.6 and 132.8 kg K/ha were not significant. Green leaf yield, cured leaf yield and grade index at 99.6 kg K/ha being on a par with 132.8 kg K/ha were significantly higher than that at lower levels of 66.4, 33.2 and 0 kg K/ha. Green leaf yield at RDF was significantly higher by 0.49 (4.61%), 1.19 (12%) and 2.77 t/ha (33.2%) than that at 66.4, 33.2 and 0 kg K/ha respectively. Cured leaf yield at RDF was significantly higher by 0.05 (2.7%), 0.15 (8.52%) and 0.4 t/ha (26.5%) than that at 66.4, 33.2 and 0 kg K/ha respectively. Grade index at RDF was significantly higher by 0.08 (5.8%), 0.21 (16.8%) and 0.44 t/ha (43.1%) than that at 66.4, 33.2 and 0 kg K/ha, respectively. Green leaf yield, cured leaf yield and grade index at 160 kg K/ha was higher by 0.21 (1.9%), 0.04 (2.1%) and 0.03 t/ha (2.0%) as compared to recommended dose of K. These results corroborate with the findings of Kumar *et al.* (2013).

It is to be noted that the first K increment from 0 to 33.2 kg resulted in 0.25 and 0.23 kg, while the second K increment from 33.2 to 66.4 kg produced 0.10 and 0.13 kg, the third K increment from 66.4 to 99.6 kg caused 0.05 and 0.08 kg and the fourth K increment from 99.6 to 132.8 kg produced only 0.04 and 0.03 kg increase in cured leaf and grade index respectively. This is due to law of diminishing returns i.e. the yield increases less than proportionate with each successive addition of input and the total return increases but at a diminishing rate. Application of 99.6 and 132.8 kg K/ha being on a par recorded higher green leaf/ cured leaf and grade index/ cured leaf (%) as compared to 66.4, 33.2 and 0 kg K/ha. The soils of the experimental plot is low in K status, hence application of K might have increased the productivity (Kasturi Krishna *et al*. 2016). Harder *et al*., (2000) also reported that in the highly weathered soils with low K status of Yunnam province, the placement and timing of potassium application also improved access to K and hence enhanced quality of flue-cured tobacco.

Seasonal variations were observed in yield levels and the yields were higher during third season and lower during second season. The low yields during second season was due to the occurrence of cyclone at grand growth stage of the crop that adversely affected crop productivity.

Chemical quality characters

In general, mean nicotine concentration increased from P to T position, while mean reducing sugars and reducing sugars/nicotine ratio increased from P to L position and there after decreased in T position. (Table 2). The increase in nicotine content from P to T position with increased leaf height is due to the fact that the nicotine is synthesized in the roots and its rate of synthesis is accelerated after the plants are topped. Nicotine is concentrated into the remaining tissues after the tobacco is topped and desuckered. Thus, the degree of nicotine accumulation is directly related to the duration that the leaves remain on the plants after topping. As the FCV tobacco in irrigated Alfisols is topped and complete sucker control is practiced, top leaves at the tip of the plant remain for a longer period on the plant and thus the nicotine concentration is increased from P to T position with increase in stalk position (Collins and Hawks, 1993).

FCV tobacco hybrid ‘CH-1’ recorded significantly higher reducing sugars and nicotine content than cv. ‘Kanchan’ in all the plant positions. However, the reducing sugars concentration in L position was on a par in both the cultivars. Reducing sugars/nicotine ratio was higher in cv. ‘Kanchan’ as compared to hybrid ‘CH-1’. The lower RS/nicotine ratio in hybrid ‘CH-1’ was due to more proportionate increase in nicotine as compared to RS. These differences may be probably due to the genetic variations of the cultivars.

Table 1. Effect of cultivar, N and K levels on yield parameters of FCV tobacco

Treatment	Tobacco yield (t/ha)			Green leaf/ cured leaf	Grade index/ cured leaf (%)
	Green leaf	Cured leaf	Grade index		
Cultivar					
‘Kanchan’	9.41	1.63	1.19	5.77	73.01
‘CH 1’	9.23	1.63	1.21	5.66	74.23
SEm±	0.072	0.011	0.010	0.01	0.36
CD (P=0.05)	NS	NS	NS	0.03	0.99
N-level (kg/ha)					
0	3.57	0.65	0.45	5.49	69.23
40	7.41	1.31	0.95	5.65	72.52
80	9.69	1.69	1.28	5.73	75.74
120	11.11	1.91	1.46	5.82	76.44
160	11.89	2.04	1.52	5.83	74.51
K level (kg/ha)					
0	8.34	1.51	1.02	5.52	67.55
33.2	9.92	1.76	1.25	5.64	71.02
66.4	10.62	1.86	1.38	5.71	74.19
99.6	11.11	1.91	1.46	5.82	76.44
132.8	11.32	1.95	1.49	5.81	76.41
SEm±	0.15	0.24	0.02	0.02	0.76
CD (P=0.05)	0.43	0.07	0.06	0.05	2.10
Season					
First	9.97	1.86	1.48	5.36	79.57
Second	6.45	1.03	0.50	6.27	48.54
Third	11.52	2.00	1.60	5.74	80.50
SEm±	0.12	0.02	0.01	0.03	0.28
CD (P=0.05)	0.40	0.06	0.05	0.10	0.96

Lamina reducing sugars content increased with increased levels of nitrogen from 0–80 kg N/ha and it was maximum at 80 kg N/ha in X and L positions and thereafter decreased gradually up to 160 kg N/ha. Lamina nicotine content increased progressively with increasing levels of nitrogen and was maximum at 160 kg N/ha and minimum at 0 kg N/ha, while reducing sugars/nicotine decreased gradually from 0-160 kg N/ha.

It is the interplay of the N and carbohydrate metabolism as influenced by management that predetermines the quality and chemical composition of cured leaf of tobacco. Nitrate reductase is an important substrate-inducible enzyme and its activity is affected by the NO_3-N concentration of leaves and consequent availability of the amount of N in the soil (Flower, 1999). There is a negative relationship between nitrate reductase activity and the accumulation of starch in the leaves. Nitrogen is a component of the nicotine molecule and is important in its synthesis in tobacco. The concentration of nitrogen in leaves is positively correlated with nicotine and negatively with starch and sugar concentrations (Flower, 1999). Thus in the present study, an increase in the dose of fertilizer N increased the concentration of total nitrogen and nicotine and decreased the sugars in tobacco cured leaf. Lower levels of sugars are associated with higher levels of nitrogen. These results are in conformity with the findings of Kasturi Krishna *et al*. (2009, 2016) and Krishna Reddy *et al*., (2008).

Application of different K levels caused significant changes in lamina quality characters. Lamina reducing sugars content increased from P to L position and decreased in T position. Lamina reducing sugars increased gradually from 0-99.6 kg K/ha in all positions. It was maximum in L position with 99.6 kg K/ha and minimum in P position with 0 kg K/ha. Lamina nicotine content increased progressively with increasing levels of potassium and was maximum in T position with 132.8 kg K/ha (2.34%) and minimum in P position with 0 kg K/ha (1.25%). The reducing sugars/nicotine values decreased gradually from 0-132.8 kg K/ha and was maximumin L position with 0 kg K/ha (11.62) and minimum in P positions with 99.6 kg K/ha (7.79). Application of K facilitates the uptake and transport of nitrate towards aerial parts of the plant, which in turn enhances the activities of nitrate assimilating enzymes. The parallel increase in activities of nitrogen assimilating enzymes with nitrate concentration indicates that these enzymes act in a

Table 2. Effect of cultivar, N and K levels on reducing sugars, nicotine, reducing sugars/nicotine and chloride content of FCV tobacco

Treatment	Reducing sugars (%)				Nicotine (%)				Reducing sugars/nicotine				Chlorides (%)			
	P	X	L	T	P	X	L	T	P	X	L	T	P	X	L	T
Cultivar																
'Kanchan'	11.11	16.57	21.18	17.72	1.24	1.44	1.67	2.00	9.60	12.00	12.99	9.38	0.59	0.55	0.46	0.45
'CH 1'	11.39	17.28	21.13	18.45	1.35	1.55	1.84	2.18	8.89	11.59	11.80	8.69	0.62	0.58	0.49	0.49
SEm±	0.05	0.06	0.13	0.05	0.01	0.01	0.01	0.01	0.12	0.08	0.31	0.05	0.02	0.01	0.01	0.01
CD (P=0.05	0.14	0.15	NS	0.14	0.03	0.02	0.02	0.02	0.32	0.21	1.08	0.15	NS	NS	NS	NS
N-level (kg/ha)																
0	10.69	16.56	20.42	16.84	0.74	0.81	1.02	1.32	16.31	20.50	20.78	13.29	0.98	0.92	0.80	0.75
40	11.89	17.66	21.16	19.06	1.12	1.30	1.52	1.75	10.77	13.63	12.98	11.01	0.71	0.68	0.59	0.59
80	12.77	18.38	22.13	19.34	1.33	1.54	1.81	2.18	9.62	11.80	12.25	9.16	0.60	0.57	0.48	0.49
120	11.40	17.06	21.42	18.28	1.45	1.67	1.94	2.31	7.79	10.10	10.87	7.95	0.52	0.48	0.40	0.41
160	10.34	15.94	21.07	16.78	1.55	1.75	2.03	2.39	6.67	8.97	10.06	7.12	0.47	0.44	0.36	0.37
K-level (kg/ha)																
0	10.40	16.12	20.72	18.06	1.25	1.47	1.74	2.09	8.24	10.73	11.62	8.56	0.57	0.53	0.44	0.45
33.2	10.87	16.42	20.79	18.38	1.34	1.58	1.82	2.18	8.05	10.30	11.29	8.32	0.54	0.50	0.41	0.42
66.4	11.18	16.85	21.31	17.91	1.41	1.63	1.91	2.25	7.91	10.12	11.00	8.08	0.53	0.49	0.40	0.41
99.6	11.40	17.06	21.42	18.28	1.45	1.67	1.94	2.31	7.79	10.10	10.87	7.95	0.52	0.48	0.40	0.41
132.8	11.69	17.37	21.40	18.11	1.49	1.71	1.99	2.34	7.82	10.00	10.68	7.84	0.50	0.46	0.37	0.38
SEm±	0.10	0.06	0.27	0.11	0.02	0.01	0.02	0.02	0.24	0.16	0.17	0.11	0.01	0.01	0.01	0.01
CD (P=0.05)	0.29	0.12	0.75	0.30	0.07	0.04	0.04	0.05	0.68	0.45	0.48	0.31	0.03	0.03	0.02	0.02

P, Primings (first and second harvest from bottom); X, lugs and cutters (third and fourth harvest); L, leaf (fifth to 10th harvest); and T, tips (11th and 12th harvest) @ 2 leaves/harvest coordinated manner in order to assimilate N in plants and thus improved the nicotine as N is the important constituent of nicotine molecule (Kasturi Krishna *et al*. 2016).

Chlorides are well within the acceptable limits of good quality (<1.5%). The chemical quality characters were within the acceptable limits of good quality leaf. Distribution of nicotine, reducing sugars and sugars/nicotine ratio in lamina in different plant positions of cured leaf of tobacco followed the normal trend in all the treatments.

Nutrient uptake

'Kanchan' recorded significantly higher leaf, stem, root and total nitrogen, higher stem phosphorus and higher root potassium uptake than hybrid 'CH-1' where as hybrid 'CH-1' recorded significantly higher leaf, root and total phosphorus and leaf, stem and total potassium uptake than cv. 'Kanchan' (Table 3). However, N uptake by 'Kanchan' was higher by 3.70% as compared to 'CH-1' and K uptake by hybrid 'CH 1' was higher by 4.14% as compared to 'Kanchan'and can be attributed to the genetic differences among the varieties.

Application of increased levels of nitrogen from 0-160 kg N/ha caused progressive and significant increase in leaf, stem, root and total nitrogen uptake and also caused gradual increase in leaf, stem, root and total phosphorus and potassium uptake due the increase in dry matter and yield. The mean total N uptake in control plot (0 kg N/ha) was 12.9 kg/ha, while it was 73.5 kg/ha with 160 kg N/ha. Nutrient uptake by the crop is positively correlated with the dry matter production (Kasturi Krishna *et al*. 2016) and this followed the same trend in dry matter and cured leaf production showing the highest proportion of uptake at lower doses and lower proportion of uptake at higher doses. At the same level of N also K up to 99.6 kg/ha could increase the uptake of N in all the plant parts (Kasturi Krishna *et al*., 2016). In the total N uptake of 52.2 kg/ha, proportion of N accumulation in leaf, stem and root was 54.0, 25.3 and 20.7% respectively. In the total P uptake of 8.2 kg/ha, proportion of P accumulation in leaf, stem and root was 61.9, 24.4 and 13.7%, respectively. The more proportion of N and P accumulation in leaf was due to higher dry matter accumulation in leaf. Moustakas and Nizanis (2005) also reported similar pattern of uptake and distribution of N and P in plant parts.

Application of increased levels of potash caused progressive and significant increase in leaf, stem, root and total potassium uptake and also caused gradual increase in leaf, stem, root and total nitrogen and phosphorus uptake. The increase in total N and P uptake due to K fertilization is attributed to the increase in leaf and stem yields as a consequence of balanced N: K fertilization. Enhancement in uptake of N and P through K application ultimately helped in increasing the nitrogen-use efficiency. The mean total K uptake in control plot was 30.6 kg K/ha, while it was 81.5 kg K/ha with 132.8 kg K/ha. Uptake of N and K increased with increased levels of N and K (Gurumurthy and Vageesh 2007; Kasturi Krishna *et al*. 2016). Progressive increase in dose of K decreased the proportion of K

Table 3. Effect of cultivar, N and K levels on leaf, stem, root and total N, P and K uptake by FCV tobacco (pooled mean of 3 years)

Treatment	Nitrogen uptake (kg/ha)				Phosphorus uptake (kg/ha)				Potassium uptake (kg/ha)			
	Leaf	Stem	Root	Total	Leaf	Stem	Root	Total	Leaf	Stem	Root	Total
Cultivar												
'Kanchan'	28.8	13.5	10.9	53.2	4.90	2.07	1.08	8.05	44.00	10.7	5.64	60.3
'CH 1'	27.6	13.0	10.7	51.3	5.25	1.93	1.17	8.30	46.4	11.0	5.42	62.8
SEm±	0.24	0.11	0.08	0.39	0.05	0.02	0.01	0.08	0.46	0.09	0.03	0.55
CD (P=0.05)	0.65	0.29	0.23	1.08	0.15	0.06	0.03	0.22	1.27	0.24	0.08	1.53
N-level (kg/ha)												
0	6.88	3.39	2.68	13.0	2.81	1.02	0.55	4.38	22.7	4.71	2.61	30.0
40	18.2	8.59	7.02	33.8	4.78	1.77	0.95	7.29	42.6	9.35	5.04	57.0
80	27.2	12.8	10.5	50.5	5.34	2.08	1.17	8.59	51.7	11.9	6.27	69.9
120	34.5	16.3	13.3	64.1	5.51	2.27	1.23	9.01	56.8	13.3	6.57	76.7
160	39.9	18.5	15.1	73.5	5.66	2.34	1.24	9.27	58.2	13.9	6.73	78.8
K-level (kg/ha)												
0	26.8	13.3	10.9	51.0	5.10	1.94	1.15	8.19	19.1	7.23	4.22	30.6
33.2	31.4	15.0	12.3	58.7	5.48	2.18	1.24	8.91	42.1	10.5	5.46	58.1
66.4	33.2	15.1	12.3	60.6	5.45	2.16	1.25	8.85	53.0	12.1	6.01	71.1
99.6	34.5	16.3	13.3	64.1	5.51	2.27	1.23	9.01	56.8	13.3	6.57	76.7
132.8	35.5	16.3	13.2	65.0	5.57	2.25	1.31	9.12	60.5	14.3	6.82	81.6
SEm±	0.50	0.23	0.18	0.82	0.11	0.05	0.03	0.17	0.97	0.18	0.06	1.17
CD (P=0.05)	1.39	0.63	0.49	2.28	0.32	0.14	0.07	0.48	2.70	0.50	0.17	3.24

Table 4. Effect of cultivar, N and K levels on different use efficiency indices of FCV tobacco

Treatment	Agronomic-use efficiency (kg CLY increased/kg nutrient applied)		Nutrient-use efficiency or Nutrient recovery efficiency (%)		Physiological efficiency (kg CLY increased/kg nutrient taken up from fertilizer		Nutrient harvest index or Translocation index (%)		Internal efficiency (kg CLY/kg nutrient taken up)		Partial factor productivity (kg CLY/kg nutrient taken up)		N:K uptake ratio
	AUE_N	AUE_K	RE_N	RE_K	PE_N,	PE_K,	HI_N,	HI_K,	IE_N	IE_K	PFP_N'	PFP_K'	
Cultivar													
'Kanchan'	11.7	3.94	44.7	44.0	25.8	8.89	53.8	74.2	35.3	31.4	20.6	23.7	0.73
'CH 1'	12.8	4.29	45.1	50.9	27.9	8.42	53.8	74.7	36.6	30.6	20.6	23.9	0.68
N-level (kg/ha)													
0				0.49			53.2	75.6	49.9	21.5		5.37	0.43
40	16.6		52.3	22.0	31.8		53.9	74.7	38.7	23.0	32.7	10.9	0.59
80	13.1	1.47	47.0	32.7	27.8	4.46	53.9	74.0	33.4	24.2	21.1	14.1	0.72
120	10.6	3.34	42.6	38.4	24.8	8.70	53.9	74.1	29.9	25.0	16.0	16.0	0.84
160	8.69	4.36	37.8	40.2	23.0	10.8	54.3	73.8	27.7	25.8	12.7	17.0	0.93
K-level (kg/ha)													
0	7.23		31.8		22.8		52.5	62.5	29.6	49.5	12.6		1.67
33.2	9.27	6.10	38.0	68.7	24.4	8.92	53.6	72.5	30.0	30.3	14.6	43.9	1.01
66.4	10.1	4.31	39.8	50.7	25.4	8.52	54.8	74.5	30.6	26.1	15.5	23.2	0.85
99.6	10.6	3.34	42.6	38.5	24.8	8.70	53.9	74.1	29.9	25.0	16.0	16.0	0.84
132.8	10.8	2.70	43.4	31.9	25.0	8.49	54.6	74.1	30.0	23.9	16.2	12.2	0.80

uptake gradually, with the highest proportion in first increment (0-33.2 kg K/ha) and lowest in 99.6 to132.8 kg K/ha. This is because the economic yield and dry matter could not increase in tune with the rate of fertilizer N and K application following the law of diminishing return and low nutrient recovery efficiency, which resulted in lower agronomic efficiency. Further the decline in N and K recovery efficiency with increase in N and K level might be due to leaching losses of these nutrients to deeper layers beyond root zone owing to porous nature of sandy soils. In the total K uptake of 61.5 kg/ha, proportion of K accumulation in leaf, stem and root was 73.4, 17.6 and 9.0% respectively. Moustakas and Nizanis (2005) also reported the similar pattern of distribution of K in plant parts.

Higher total K uptake by the tobacco crop than N uptake indicates the importance of K in the mineral nutrition of FCV tobacco. N and K accumulation in leaf was higher than in stem and root. The soils of the experimental plot was low in N and K status, hence application of N and K might have increased the uptake of N and K by the crop (Harder *et al.,* 2000 and Kasturi Krishna *et al*., 2016).

N and K-use efficiency indices

Nitrogen and potassium use efficiencies under different levels of N and K were evaluated (Table 4) in terms of agronomic use efficiency ($AUE_{N,}AUE_K$), physiological efficiency ($PE_{N,}$ $PE_{K,}$), harvest index ($HI_{N,}$ HI_K), internal efficiency ($IE_{N,}$ IE_K), partial factor productivity ($PFP_{N,}$ PFP_K) and recovery efficiency ($RE_{N,}$ RE_K). $AUE_{N,}$ $AUE_{K,}$ $RE_{N,}$ RE_K, PE_N, HI_N, $HI_{K,}$ IE_N, PFP_N and PFP_K were slightly higher for 'CH 1' than cv. 'Kanchan', where as PE_K and $IE_{K,}$ were slightly higher with cv. 'Kanchan' than 'CH-1'. The hybrid 'CH-1' showed relatively more nutrient use efficiency indices and differences between two varieties in these values might be attributed to the genetic differences of the cultivars. Kumar *et al*., (2015) also reported that the nutrient use efficiency was higher in hybrids than the varieties in case of maize.

The $AUE_{N,}$ $PE_{N,}$ IE_N and PFP_N values ranged from 8.69 to 16.6, 23.0 to 31.8, 27.7 to 49.9 and 12.7 to 32.7 kg/kg; RE_N and HI_N values ranged from 37.9 to 52.3 and 53.2 to 54.3%, respectively. The AUE_K, $PE_{K,}$ IE_K and PFP_K values ranged from 2.70 to 6.10 8.49 to 8.92, 23.9 to 49.5 and 12.2 to 43.9 kg/kg; RE_K and HI_K values ranged from 31.9 to 68.7 and 62.5 to 74.5% respectively. All these indices except HI_N and HI_K were lower at higher doses of N and K and increased with decrease in the level of N and K. The

HI_N and HI_K remained more or less same (53.2 to 54.3% for N and 72.5 to 74.1% for K) across all levels of N and K. However, at no K control HI_K remained comparatively low i.e. 62.5%. This implied that about 53.2 to 54.3% of total N uptake and 72.5 to 74.1% of total K uptake was trans-located to economic part (i.e. leaf) in all the treatments. N and Kapplication increased their uptake with each successive addition in level up to 160 kg N/ha and 132.8kg K/ha. But the use efficiencies showed the reverse trend and the maximum values of use efficiencies of both the nutrients were noticed at 40 kg N and 33.2 kg K/ha. The AE, PE, IE, PFP and RE declined steadily with successive increase in level of both N and K. This is because the leaf yield could not increase in tune with the rate of fertilizer application following the law of diminishing return and low nutrient utilization efficiency which resulted in lower values of N and K use efficiencies. The decline in N and K recovery efficiency with increase in level of N and K might be due to leaching losses of these nutrients to deeper layers beyond root zone owing to the porous nature of sandy soils in addition to law of diminishing returns. These results corroborate with the findings of Farrokh and Farrokh (2012).

Further, it is observed that at a given dose of N (120 kg N/ha), increasing the level of K from 0 to 132.8 kg K/ha gradually increased the AE_N, RE_N, PE_N, PFP_N and decreased the N: K uptake ratio. And at a given dose of K (99.6 kg K/ha) increasing the level of N from 0 to 160 kg N/ha also gradually increased the AE_K, RE_K, IE_K, PFP_K and N: K uptake ratio. The increase in total N uptake due to K fertilization is attributed to increased yield as a consequence of balanced fertilization. Enhancement in uptake of N through K application ultimately helped in increasing the N use efficiency indices (Brar *et al*., 2011). Potassium is essential for plant growth and greatly required during the growth, vegetative and reproductive stages since it is engaged in osmotic adjustment, stomatal mechanism, photosynthesis, enzyme activation and meristem growth. The total K uptake increase due to N fertilization is attributed to the increase in availability of nitrogen, a potent stimulant of growth. However, to achieve maximum efficiency in tobacco production an appropriate balance in amounts of N and K must be available in the soil as there is strong interaction between these 2 nutrients for the growth of the crop.

In FCV tobacco the RE_N values ranged from 37.8 to 52.3% and RE_K values varied between 31.9 and 68.7% under irrigated Alfisols. The RE_N is only 30–40% in rice and 50–60% in other cereals. The RE_K varied from 60 to 80% in other crops. These findings corroborate with reports of Brar *et al*. (2011). Prasad and Shivay (2016) also reported that the fertilizer N use efficiency is less than 50%.

Both cv. 'Kanchan' and hybrid 'CH-1' performed on par and would require 120–26.2–99.6 kg N-P-K/ha when grown after sunnhemp *in-situ* green manure for getting optimum productivity, better grade index with acceptable chemical quality parameters, optimum nutrient-uptake and nutrient use efficiencies under irrigated Alfisols of Andhra Pradesh.

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