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Carbon capture and seasonal 'C' offset by *Foeniculum vulgare* grown with N, FYM and their integration

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ABSTRACT

Field experiments were carried out on Typic Haplustepts soil having texture sandy loam with various nitrogen levels i.e. 0, 40, 60, 80, 100, 120 kg ha^{-1} and also integrated use of N + FYM levels taking fennel (Foeniculum vulgare) variety AF-1 as test crop. These treatments were compared with control. Results revealed that seed yield and biomass increased with increasing doses of N levels which was > 1.5 times more with 120 kg N as compared to control. Likewise N+FYM also gave more yield than their individual applications. Carbon content was lower and accumulation in seed, stover including total uptake was higher beyond the 60 kg N ha^{-1}. Carbon content was lower in stover with higher dose of N + FYM and the accumulation in seed and stover was higher. Carbon captured by fennel was more with 12 t FYM applied either with 40 or 80 kg N ha^{-1}. Total or net soil carbon pool was more with higher levels of N, FYM and their combinations. Net carbon offset by the crop and soil in a season was more beyond the 60 kg N or either level of FYM and also in combination with N. Mean carbon offset by fertilizer N was 4.8 t ha^{-1} and 5.1 t ha^{-1} by N + FYM. Interestingly carbon content in seed was slightly lower or equal to the stover, hence a common thresher is not applicable to separate them easily and the second most important finding is that combine use of N and FYM captured more C seasonally than the fertilizer N alone, while fertilizer N has more manufacturing C foot print than the manure. Hence, integrated use of N and FYM has multi-faced benefits for reducing C foot print of input, captures more C during a season easily accessibility to the farmers, improves the crop yield and soil properties.

Keywords: Nitrogen, carbon capture, FYM, CO_2 offsets, *Foeniculum vulgare*, fennel

INTRODUCTION

Climate change is a global concern and challenge for humans to survive on Earth. Our development in all spheres of life, along with the over exploitation of natural resources, results in a loss of nature's resilience power. Unwise use of energy and resources resulted in massive emissions of greenhouse gases (CO_2, CH_4, N_2O etc.) and an increase in troposphere temperature. This has resulted in less rain in some parts of the planet, melting ice caps, receding glaciers, sea level rise, increasing deserts, a shift in weather patterns and occurrences of extreme events. Plant-rich environments such as forests, grasslands and rangelands absorb approximately 25% of global carbon emissions. When plant's leaves and branches fall off or die, the carbon stored in them is either released into the atmosphere or transferred to the soil. Plants sequester carbon in soil through photosynthesis, which can be stored as soil organic carbon (SOC). Although agro-ecosystems can degrade and deplete SOC levels, the carbon shortage provides an opportunity to store carbon through new land management practices. Soil can also store carbon as carbonates. Carbonates of this type are formed over thousands of years as CO_2 dissolves in water and percolates in the soil, mixing with calcium and magnesium minerals to form "caliche" in dry and arid soil. SOC is the key element that determines soil quality, fertility, agricultural profitability, and atmospheric CO_2 fixation. The SOC affects physio-chemical and biological properties of soil which simultaneously improves soil structure, water and nutrient retention capacity and land use. Poor land management practices, overexploited, degraded and irreversibly lost occurs due to inappropriate, industrial activities and land use changes that lead to soil sealing, erosion, contamination and loss of organic carbon. The agriculture sector contributes significantly to global carbon emissions from diverse sources such as product and machinery manufacture, transport of materials and direct or indirect greenhouse gas emissions (Hillier *et al.,* 2009). However, detailed studies into the contribution of specific farming activities during crop production to the overall

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footprint are only recently being conducted by Adler *et al.,* (2007). It is also possible that, to some extent, reduction in the carbon footprint is correlated with other environmental benefits. For example, reduced agrochemical inputs is likely to decrease the carbon footprint and may also have a beneficial effect on the biodiversity within and around arable fields (Squire *et al.,* 2000, Robinson and Sutherland, 2002, Marshall *et al.,* 2003). It is therefore important to be able to identify the environmental impact of different management approaches. A sizable amount of 'C' sequester in soil and stored in macro and micro soil aggregates could be a one of the important option for the store house of 'C' in soil including biological 'C' sequestration or 'C' captured by a crop for a limited period. Therefore, present investigation was carried out with input management in soil by manures and fertilizers to investigate the 'C' accumulation in both soil and plant so as to calculate the seasonal offset of 'C' by growing fennel crop.

MATERIAL AND METHODS

Location and climate

Field experiments were carried out during *Rabi* season of 2016-2017 and 2017-2018 at ICAR-National Research Centre on Seed Spices, Tabiji, Ajmer, Rajasthan, India. This was laid between 74° 35'39" to 74° 36' 01"E longitude and on 26° 22'12" to 26° 22' 31" N latitude. Climate of the Ajmer area characterized as semi-arid. However, it is located at a transition zone of arid and semi-arid reasons by rainfall pattern vary widely years to year. The average annual rainfall of the area is 536 mm and most of it (85-90%) receives from June to September. July and August are most rainy months contributing 60.0% of the average rainfall. Soil moisture control section remains dry for more than 90 cumulative days and hence moisture regime classified as Ustic. Mean annual temperature is 24.5 to 25.0°C. January is the coolest month of the season and temperature remains around 5.0-7.0°C or sometimes, frost also occurs in this month.

Treatments and cultural practices

The field experiments were carried out on Typic Haplustepts soil of Ajmer, Rajasthan, India. The first experiment was carried out with six levels of N i.e., 0, 40, 60, 80, 100 and 120 kg ha^{-1} and second experiment with N_{40}, N_{80}, FYM_8, FYM_{12} and their combinations. These six and eight treatments were compared with control. The treatments of both the experiments were arranged in a Randomized Block Design (RBD) with three replications. Seeds of the crop (Ajmer Fennel-1) were sown in the 50 cm line to line apart and distance from plant to plant was maintained at 15 cm. Cultural practices were uniformly followed during the growing seasons in both the years. The crop was harvested when seeds were matured. After harvest, seeds were separated from the straw by beating of bundles thereafter winnowing.

Soil and plant analysis

Soil samples were collected from the surface (0-15 cm depth) before sowing of seeds and various crop growth stages including at maturity during both the years. Samples were air dried and powdered with wooden mortar and pestle and passed through a 2 mm stainless steel sieve. Experimental soil was analyzed for texture (International Pipette Method), EC and pH (Richards, 1954), organic carbon content by rapid chromic titration (Walkley and Black, 1934), available N by alkaline permanganate (Subbiah and Asija, 1956), available P by 0.5 M NaHCO3 extractable P (Olsen, *et al.,* 1954), available K by 1N NH4OAc extracts method (Jackson, 1973), available micro-nutrients by DTPA (Lindsay, and Norvell, 1978). Plant carbon content (%) was estimated by CHNS analyzer (ThermoFisher Scientific make). Texture of experimental soil was sandy loam to loamy sand. Soil EC, pH and organic carbon were 0.29 dSm^{-1}, 8.2 and 0.24%, respectively. However, soil available N, P and K were 112.2, 9.6 and 239.3 kg ha^{-1}, respectively. Micronutrient status like iron, zinc, manganese and copper of the soil was 10.3, 1.75, 21.35, 2.09 kg ha^{-1}, respectively.

General calculations for 'C' captured and seasonal off-set

Carbon content in plant multiply with plant biomass (root, shoot and seed) for the calculation of its accumulation in various plant parts and finally carbon captured by the plant and soil was calculated. Soil organic carbon pool was calculated by the bulk volume of soil and soil organic carbon content in rhizospheric soil. Total carbon offset during the season was calculated by adding ‘C’ accumulation in plant and the soil ‘C’ pool. Whereas net ‘C’ offset was calculated by subtracting of initial soil ‘C’ pool from the total ‘C’ captured by soil after experiment.

Statistical Analysis

The data obtained during both the years from both the experiments were pooled and analyzed by ANOVA. Treatment differences were expressed for Least Significant Differences (LSD) at 5% probability to determine the significance among the treatment means for both experiments (Cochran and Cox, 1987).

RESULTS AND DISCUSSION

Yield, carbon content and C captured by fennel

Seed and stover yield of fennel increased with each successive level of N (Fig. 1). Seed and stover yield was highest with 120 kg N ha^{-1}. Because of N is an essential component of chlorophyll, higher N input enhanced higher carbon assimilation and other organic compounds. Rai *et al.,* (2002) also found higher growth parameters with nitrogen doses in fennel. Seed yield was highest with combine use of 12t FYM and 80 kg N ha^{-1} and their combinations as compared to control (Fig. 2). This might be due to plant growth was more with either N and FYM or their combinations leads to more photosynthates and ultimately more yield.

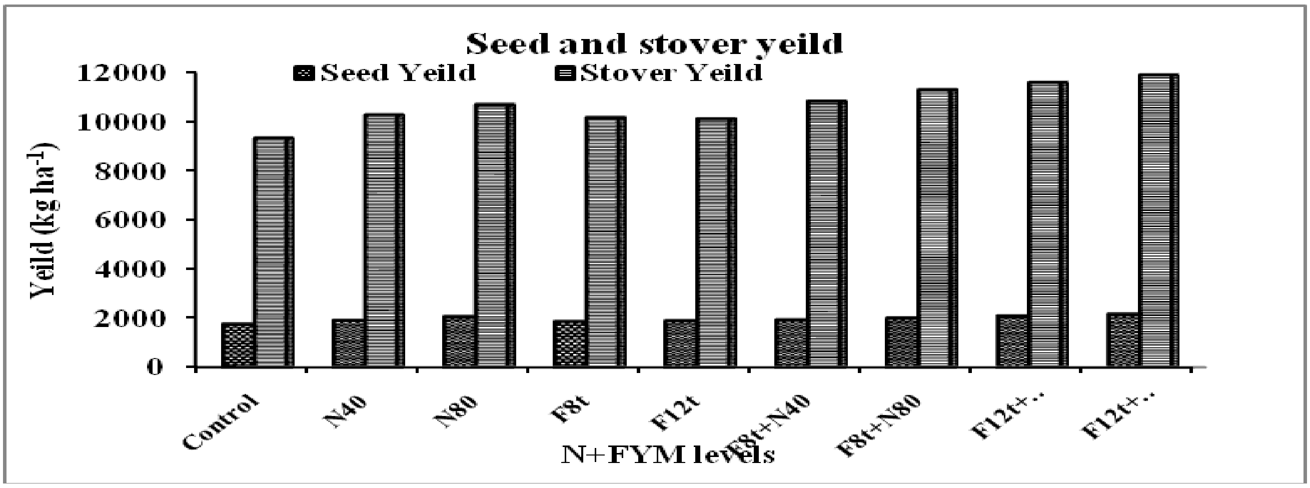

Fig. 1: Seed and stover yield of fennel with applied levels of N+FYM

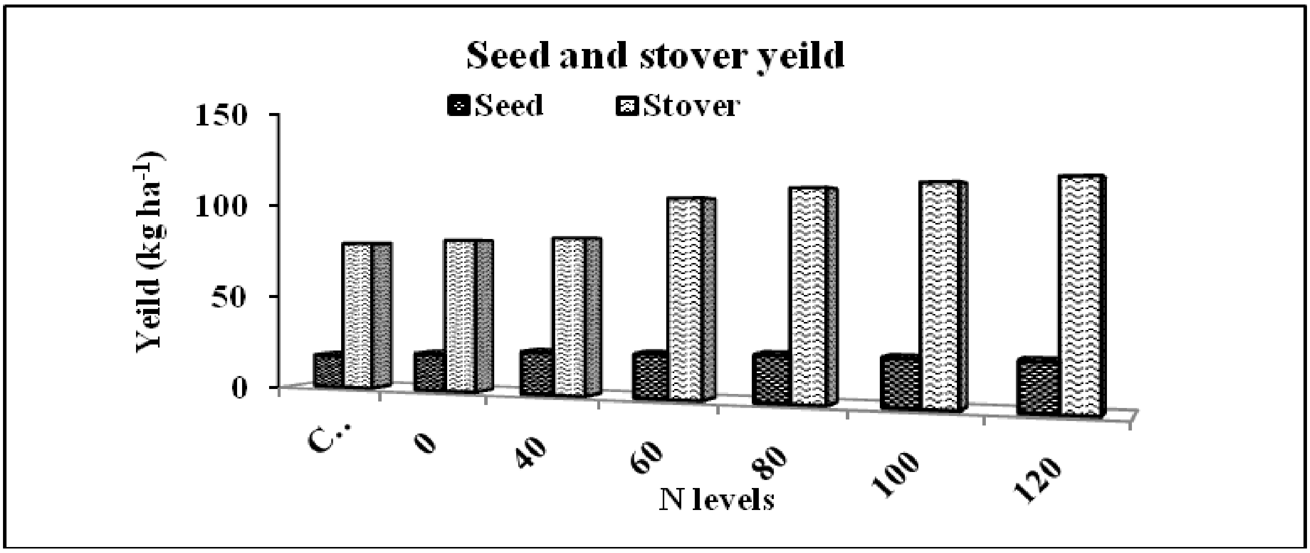

Fig. 2: Seed and stover yield of fennel with applied levels of N

Table 1: Carbon accumulation in plant and SOC pool with N levels

Treatments	'C' uptake (kg ha^{-1})		C captured by crop (kg ha^{-1})	SOC pool (kg ha^{-1})		
	Seed	Stover		Before crop	After crop	Net balance
Control	740.3	3152.8	3893.1	448.0	486.0	38.0
N_0	836.1	3196.3	4032.4	450.0	653.8	203.8
N_{40}	944.8	3244.4	4189.2	451.0	778.8	327.8
N_{60}	958.8	3961.8	4920.6	456.0	781.8	325.8
N_{80}	1002.3	3929.4	4931.6	458.0	842.5	384.5
N_{100}	1014.0	3948.3	4962.3	460.0	823.4	363.4
N_{120}	1012.3	3785.1	4797.4	465.0	847.6	382.6
CD at 5%	46.20	463.45	467.76	NS	73.8	73.8

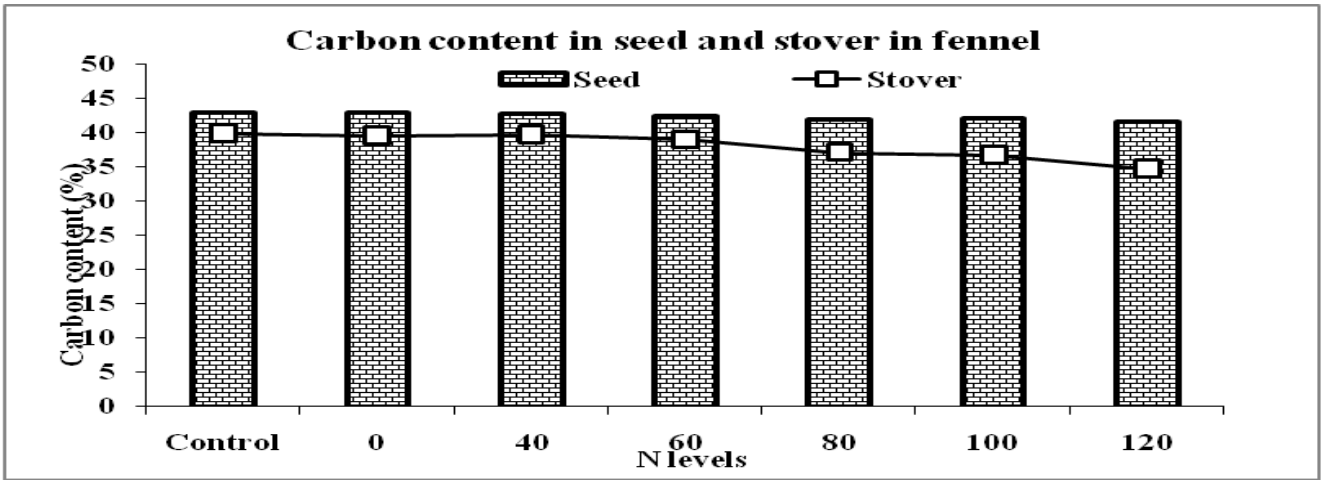

Fig. 3: Carbon content in seed and stover in fennel with N levels

Carbon content in seed decreased with increase in N doses marginally, however it was only lower significantly at 120 kg N ha^{-1} (Fig. 3). Carbon content in stover decreased beyond 80 kg N ha^{-1} over the other lower levels. It was at par with 80, 100 and 120 kg N ha^{-1}, moreover it was decreasing in order. Carbon accumulation in seed was more with all the levels of N as compared to control (Table 1). Accumulation in seed at 80 kg N was more than 60 kg N ha^{-1} which was at par with rest of the higher doses of N. Carbon accumulation in stover was more with 60 kg N ha^{-1} and the beyond the higher levels of N. However, there was no statistical variation within these treatments. This is because of higher seed yield and biomass accumulation in fennel with applied N. In contrast to 'C' accumulation in seed and stover carbon content (%) decreased with increase in doses of N might be due to N and other mineral nutrients including other biochemical compounds were more with higher doses of N, hence it is obvious that the 'C' content in seed and stover decreased with increase in doses of N in fennel (Feng *et al.,* 2018). Total 'C' captured by the fennel was ranged from 3893.1 kg ha^{-1} to 4962.3 kg ha^{-1}. The captured by the crop was highest at 100 kg N ha^{-1} which was at par with 60, 80 and 100 kg N ha^{-1}. Though content decreased with higher levels of N, yet uptake was more due to proportionate corresponding value of seed yield and biomass accumulation was more with higher doses of N, hence uptake/C captured was more with higher N (Aishwath *et al.,* 2012).

In the second experiment with N and FYM and their combination, C content in seed marginally decreased with increase in doses of N and FYM and their combination (Fig.4). Whereas, carbon content per cent was lower with 12t FYM or the combine use of either doses of N and FYM. This is obvious that higher input nutrients to the plant uptake of these elements was more and the proportion 'C' content was lower than the lower doses of farmyard manure and N fertilizer. Carbon accumulation in seed and stover was more with 80 kg N applied alone or 40 kg N applied with 12t FYM (Table 2). The accumulation was also more in seed when 80 kg

N was applied with 12t FYM. This is because of more seed yield and biomass accumulation with these higher doses of N and FYM. These findings are in accordance with Aishwath *et al.,* (2015). Total 'C' captured by fennel during the season was higher with application of 80 kg N ha^{-1} alone or its combine use with 12t FYM. However, 40 kg N applied with 12t FYM, fennel captured more carbon over the control. Moreover, these treatments were at par with other treatments. This might be due to 'C' content was inversely related to higher input in fennel either alone or combine use of N and FYM. Here, the most important findings are; 'C' captured by single use of N levels was lower than the combine use of N and FYM, indicates that integrated use of chemical fertilizers with manure was more beneficial not only for yield or economic return but also environment concern. Aishwath *et al* (2018) reported higher C captured by the crop or biological C sequestration was more with higher input of manure in coriander.

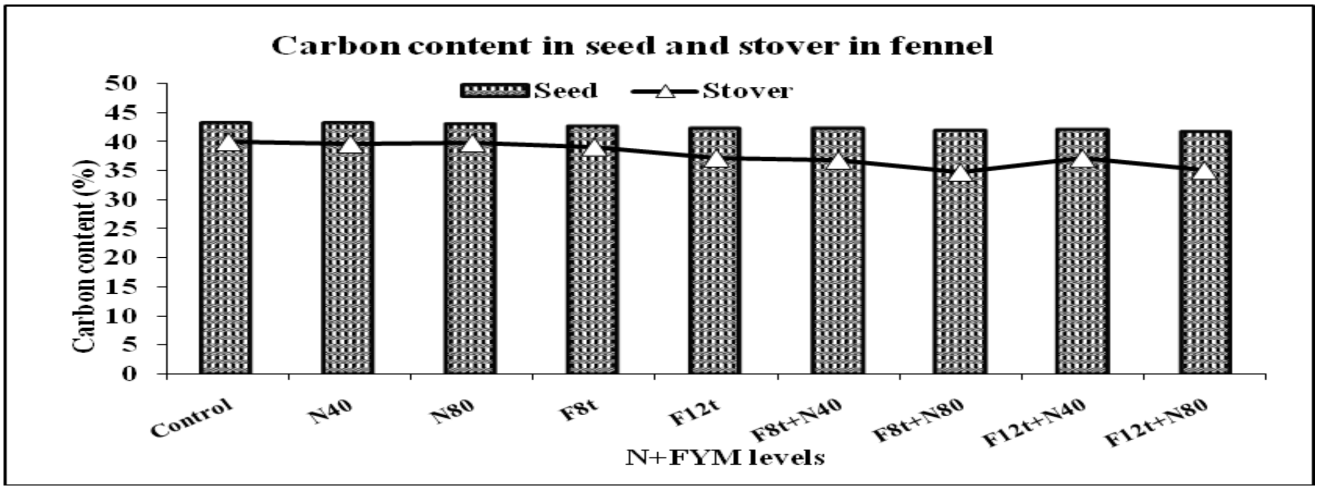

Fig. 4: Carbon content in seed and stover in fennel with N+FYM levels

Soil 'C' pool with N and FYM

The initial soil organic carbon pool was did not vary with statistically, however it was in increasing order with higher doses of applied N (Table 1). This might be due to previous experiments were carried out on piece of land was having similar treatment with coriander crop. The range of 'C' pool was 448.0 to 465 kg ha^{-1}. Application of graded levels of N, soil organic carbon pool increased with its higher doses and was also more at harvest than the initial level. However, there was no statistical variation within the treatments where 40 kg N to 120 kg N ha^{-1} was applied. Based on the mean values, 38.9 per cent carbon pool increased by N application over the initial soil carbon pool. This is because of more N input improved root biomass and seminal root decayed till the harvest of crop improved the soil 'C' pool (Sharma *et al.,* 2018; Aishwath *et al.,* 2015). The net soil carbon pool increased with higher doses of N as compared to control. Moreover, there was no statistical variation with 40-120 kg N ha^{-1}. The range of net 'C' pool was vary from 38.0 to 384.5 kg N ha^{-1} with 80 kg N ha^{-1}. There was no statistical variation in the initial pool of soil carbon in second experiment on integrated use of N and FYM (Table 2). The soil carbon pool at the time of crop harvest was 29.8% more than the initial level. However, application of N alone did not influence the soil 'C' pool. Application of either dose of FYM improved the soil 'C' pool in combination with N doses. Moreover, highest 'C' pool was with 12t FYM and 80 kg N ha^{-1}, which was at par with 12t FYM and 40 kg N ha^{-1}. The change in net carbon pool was calculated, which was enhanced with either dose of FYM alone or in combination with N levels over the control and absolute control. The highest pool was with highest doses of N and FYM (12t FYM+80 kg N ha^{-1}) which was at par with combine use of 12t FYM and 40 kg N ha^{-1}, rest of the treatments remained at par. This might be due to balance nutrition of fennel yielded more root biomass contributed more soil organic carbon per cent and ultimately soil carbon pool. Aishwath *et al* (2020) also reported similar results with organic manures in anise crop.

Table 2: Carbon accumulation in plant and SOC pool with N+FYM levels

Treatments	'C' uptake (kg ha^{-1})		C captured by crop (kg ha^{-1})	SOC pool (kg ha^{-1})		
	Seed	Stover		Before crop	After crop	Net balance
Control	757.0	3738.7	4495.6	515.2	627.2	112.0
N_{40}	822.2	4084.0	4906.3	515.3	634.7	119.4
N_{80}	883.5	4262.8	5146.2	516.0	679.5	163.5
F_8	793.0	3968.7	4761.7	518.0	694.4	176.4
F_{12t}	799.6	3768.8	4568.4	521.0	731.7	210.7
F_{8t}+N_{40}	815.2	3985.0	4800.2	522.0	724.3	202.3
F_{8t}+N_{80}	840.2	3924.9	4765.2	525.0	739.2	214.2
F_{12t}+N_{40}	873.8	4306.7	5180.5	527.0	918.4	391.4
F_{12t}+N_{80}	895.6	4170.1	5065.7	529.0	925.9	396.9
CD at 5%	84.87	468.89	486.13	NS	60.5	60.5

Seasonal carbon offset with N and FYM

Seasonal carbon offset was also influenced by application of N levels, which was more with higher doses of N as compared to lower level (40 kg N ha^{-1}) and control (Fig. 5). There was no statistical variation observed within 60-120 kg N ha^{-1}, it was more over the 40 kg N and controls. This is because of higher biomass accumulation in plant by N application as well as root biomass also contributed more 'C' in soil resulted higher 'C' offset with applied N. The 'C' offset ranged from 3.93t ha^{-1} to 5.3t ha^{-1} with increasing doses of N.

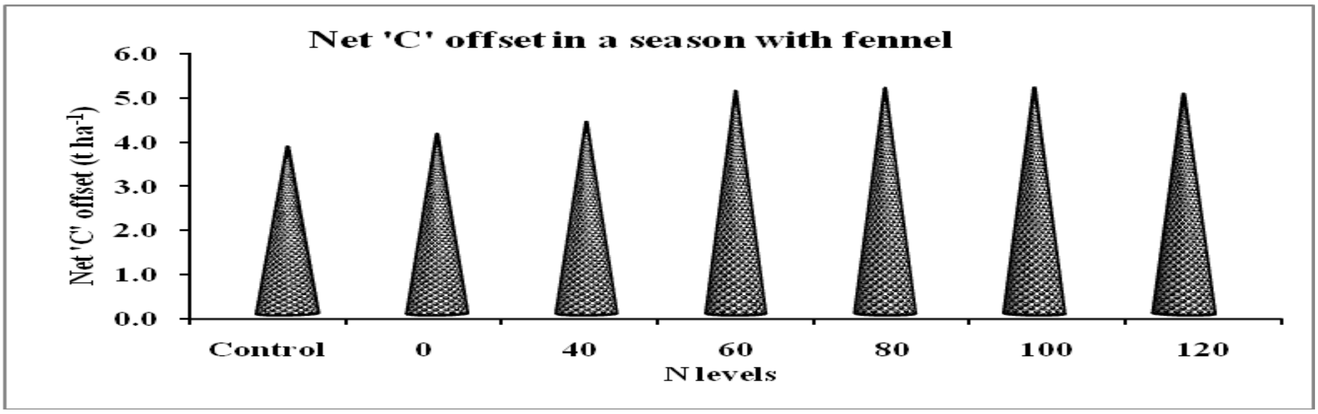

Fig. 5: Net 'C' offset in a cropping season with applied N levels

In the second experiment with N and FYM, seasonal 'C' offset was more with 80 kg N ha^{-1} alone and 12t FYM integrated with either 40 or 80 kg N ha^{-1} (Fig. 6).

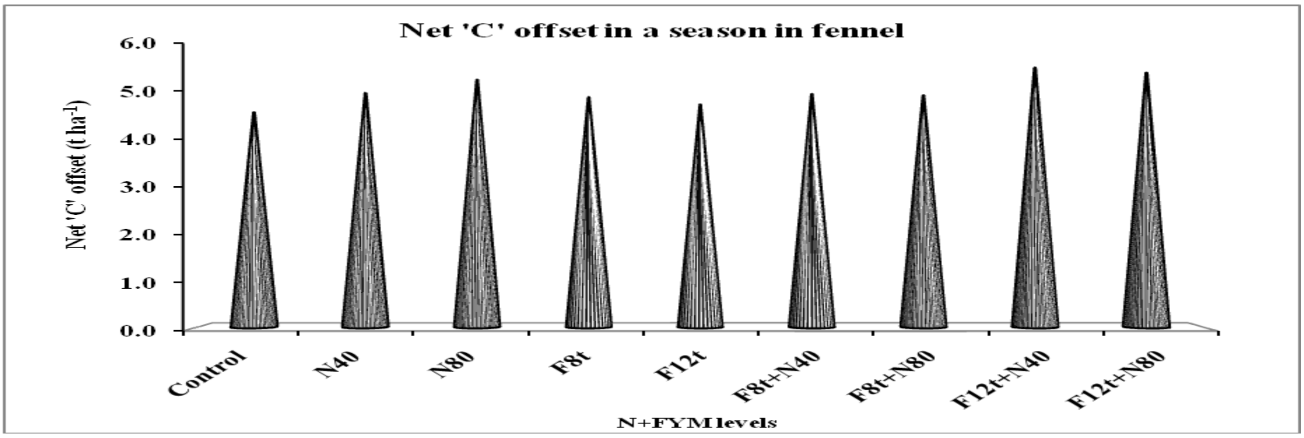

Fig. 6: Net 'C' offset in a cropping season with applied N+FYM

There was no statistical variation with use of either dose of N along with 8t FYM as well as 12t FYM applied alone in fennel. This is because of more biomass accumulation in under and above ground by the crop. Based on the both of the experiment conducted with N levels and in integration of FYM, integrated use of fertilizer and manure contributed 5.5% more seasonal offset than the fertilizer N applied alone. This might be due to balance nutrition accumulated more crop biomass (root & shoot) and seed yield captured more 'C' by the fennel and contributed to cause. Besides that 'C' foot print of fertilizer production more than the manure. The 'C' offset ranged from 4.61 to 5.57t $ha^{-1}$with integrated use of N and FYM (Hillier *et al.,* 2009 and Aishwath *et al.,* 2012).

Conclusions

Carbon content was lower and uptake was more in fennel with application of higher doses of N and FYM and their combinations. Carbon capture by the crop and soil was more with higher input of N and FYM. Therefore, seasonal C captured by the crop was more with integrated use of N and FYM rather than fertilizer N alone. Combine use of manures and fertilizers have positive effect on fennel yield and biomass accumulation by improved soil fertility. Hence, integrated use of fertilizer and manures is advisable for crop yield and environment concern.

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