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MULCHES AND NUTRIENTS AFFECT THE SOIL ENVIRONMENT, CROP PERFORMANCE AND PROFITABILITY OF CAULIFLOWER

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ABSTRACT

Crop yields are limited by water, temperature and nutrient availability. Soil mulching (with plastic or straw) reduces evaporation, modifies soil temperature and thereby affects crop yields. Reported effects of mulching are sometimes contradictory, likely due to differences in climatic conditions, soil characteristics, crop species, and also water and nutrient input. Two years field experiment was established at Himachal Pradesh, India under twelve treatment combinations of mulch and nutrient level were practised in a randomized block design. Four types of mulches (*i.e.*, black plastic mulch-BP, grass mulch-GM, pine needle mulch-PN, and unmulched control-UM) and three levels of nutrients (*i.e.*, 125% of recommended dose of NPK- N_1, 100% recommended dose of NPK -N_2 and 75% of recommended dose of NPK- N_3) were replicated thrice. Results of two years data revealed that all mulches maintained comparatively higher *in situ* soil moisture and black plastic mulch conserved the highest moisture content which was 21.3% as compared to unmulched in 0-15 cm soil depth. Mulches favorably moderated the soil temperature where black plastic mulch recorded the highest temperature at 7:30 hrs and 14:30 hrs during both the years at 15 cm depth. Grass and pine needles mulches reduced the soil bulk density and improved the soil organic carbon over unmulched control. Availability of SO_4^{2-} -S and Ca were improved under mulch, nutrient levels alone and their combinations when compared to unmulched control and 75% NPK nutrient levels. Mulching along with different levels of NPK nutrients improved the growth attributes, increased the productivity and uptake of secondary nutrients of cauliflower. Black plastic mulch in combination with 125% of recommended dose of NPK obtained the highest curd yield (26.7 t/ha) which well reflected to more favourable economics as compared to other treatment combinations.

Key words: Cauliflower, Mulches, Nutrients, Moisture, Temperature, Economics.

INTRODUCTION

The commercial cultivation of cauliflower as off season crop in mid hills of Himachal Pradesh for remunerative returns, more demand in the market even during the dry season, and increased nutritional awareness of people have attracted the farmers to bring large area under cauliflower cultivation. But owing to poor irrigation facilities which are just limited to 21% of the total cultivated area, the crop yield is poor and variable. The farmers are largely dependent upon rains and are unable to achieve higher yields of better quality under rain fed conditions. The uneven distribution of rains with common dry spells in winter season, occurrence of sub optimal soil temperature and poor retentivity of hill soils for water and nutrients are the major constraints in increasing crop yield. The other major factors that have stalled the growth and productivity of winter season crop in mid hills are low soil temperature which effects critically the seed germination, seedling emergence and early plant growth than on latter stages of the growth. Proper management of soil and water to overcome these constraints has necessitated *in situ* moisture conservation through the application of various kinds of mulches *viz*., crop residues, field grasses, pine needles, plastic sheets, etc. The practice of mulching can play an important role in meeting the partial irrigation water requirement, moderating soil temperature, enhancing availability of applied and native nutrients, and ultimately increased the crop growth, yield and net return. Different types of materials such as wheat straw, rice straw or husk, plastic film, grass, wood, sand, etc. are used as mulch (Uwah and Iwo, 2011).

The plastic mulch is used widely in many countries for conserving soil moisture and to decrease the cost of weeding and ultimately to lower the cost of crop production. Vegetable crops are generally infested with a variety of annual, biennial and perennial weeds. Weeds by virtue of their competitive habit compete fiercely with crops for space, nutrients, light and moisture; thereby drastically reduce the productivity of crop. In the presence of weeds even liberal application of fertilizers to vegetable crops fails to derive full benefits of applied nutrients. Application of mulches significantly reduced the weed population (Mohanty *et al*. 2002).

Organic mulches, improves soil quality and productivity through favorable effects on soil properties (Sinkeviciene *et al*. 2009). Favorable effects of crop residue mulching on soil organic carbon (SOC) and water retention have been reported for the surface layer (Saroa and Lal, 2003). Organic mulch not only results in increased yield, improved soil water content and increased minimum soil temperature but also directly changes soil biological characteristics and fertility (Grassini *et al*. 2009).

Fertilizer application is more effective when applied to mulched soil than bare soil. Mulching and fertilizer application together promoted growth and development of crops (Liasu and Achakzai, 2007). Increased soil water storage due to mulching increased the availability and uptake of nutrients by plants (Tan *et al*. 2009). The combination of mulch with NPK fertilizers provides additional nutrients and humic material through decaying of mulch and thus provides sustainable source of macro and micro nutrients to crops in addition to increasing the nutrient retention capacity of the soil (Atayese and Liasu, 2001) and also shows higher productivity and profitability of crop. Very few have attempted to investigate the combined effect of mulches and nutrient levels on soil and crop growth. This study evaluated the feasibility of using alternative field management practices to contribute towards vegetable security and sustainable horticulture. Therefore, the aim of the study was to evaluate the effect mulches and nutrient levels on soil environment, crop growth and yield, and profitability.

MATERIALS AND METHODS

Study site characteristics: Field experiments were established during two crop years (2009-10 and 2010-11) at the experimental farm of Department of Soil Science and Water Management, Dr. Y. S. Parmar University of Horticulture and Forestry, Solan (Himachal Pradesh), India. It is located at 30° 52' N latitude and 77° 11' E longitude and elevation of 1175 m above mean sea level having average slope of 7-8%. The area falls in sub-tropical, sub-humid agro-climatic zone of Himachal Pradesh. The average annual rainfall of the area is about 1100 mm and about 75% of it is received during the monsoon period (mid June-mid September). Winter rains are meagre and received during the months of January and February. The soils of area belong to Typic Eutrochrept at sub group level according to Soil Taxonomy of USDA, having gravelly sandy loam in texture. Salient physical and chemical properties of the experimental soil of 0-15 cm depth are presented in Table 1.

Table 1. Physico-chemical properties of experimental soil (0-15 cm depth before the start of experiment).

Properties	Value
Sand (%)	43.8
Silt (%)	31.7
Clay (%)	24.5
Textural class	Gravelly sandy loam
Organic carbon (g/kg)	7.90
pH (1:2.5)	6.88
Bulk density (Mg/m^3)	1.28
Porosity (%)	42.6
Water holding capacity (%)	44.0
Moisture retention at 0.33 bar (w, %)	21.3
Moisture retention at 15 bar (w, %)	6.40

Treatments and Experimental design: The experiment was laid out with 12 treatments replicated thrice in randomized block design during 18th December 2009 to 17th April 2010 and 30th October 2010 to 18th February 2011 (two seasons). The treatments comprised combinations of four types of mulches, *viz*., black plastic mulch (BP), grass mulch (GM), pine needles (*Pinus roxburghii*) mulch (PN), unmulched control (UM) and three levels of nutrients, *i.e*., N_1 (125% of recommended dose of NPK), N_2 (100% recommended dose of NPK) and N_3 (75% of recommended dose of NPK). The layout design of treatments is given below:

Replication	Treatment combinations											
R_1	BPN_1	PNN_2	UMN_1	GMN_2	BPN_3	UMN_3	GMN_1	UMN_2	BPN_2	PNN_1	GMN_3	PNN_3
R_2	GMN_2	BPN_2	PNN_1	GMN_3	GMN_1	BPN_1	UMN_1	PNN_2	UMN_3	PNN_3	UMN_2	BPN_3
R_3	UMN_2	PNN_1	GMN_2	UMN_3	PNN_2	UMN_1	BPN_3	GMN_3	BPN_2	BPN_1	GMN_1	PNN_3

Lay out of treatments

Crop management Field preparation: Before the execution of experiment, the field was well ploughed by tractor followed by planking 15 days prior to actual date of transplanting of seedlings. Weeds, stones, pebbles, etc. were removed from the field. Thirty six raised plots of dimension of 3.0 × 2.5 m were made.

Nutrient application: Recommended doses (100%) of farm yard manures, nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) is 25 t, 125 kg, 75 kg and 65 kg/ha, respectively, and were applied as per the treatments of the experiment. The nutrients N, P, K were applied in the form of calcium ammonium nitrate, single super-phosphate and muriate of potash, respectively. Entire dose of P and K fertilizers was applied at the time of field preparation. The N fertilizer was applied in two equal split doses, first dose at the time of transplanting and second dose one month after transplanting.

Mulching: The UV resistant black plastic sheets were cut in rectangular shape, slightly larger than the dimension of plots and holes were made by scissors to fit the plants in the holes. Mulch sheet was laid in the plots before the transplanting of seedlings. The air-dried grass and pine needles mulch materials were spread evenly in the plots to have uniform mulch @ 10 t/ha just after the establishment of the seedlings. The plastic mulch was removed after the completion of experiment. The partially decomposed grass mulch was allowed to remain in the plot, which was later on mixed with soil. However, undecomposed pine needles mulch was removed and applied a fresh during the second year.

Transplanting: Three week-old seedlings of Sweta cultivar were transplanted in plots of dimension of 3.0 m × 2.5 m at spacing of 60 cm × 45 cm on 18th December 2009 and 30th October 2010.

Irrigation: After transplanting (upto two weeks after transplanting), the crop was irrigated daily with sprinkle, thereafter the crop was irrigated at 15-20 days interval with 4 cm of irrigation depending upon the prevailing climatic conditions. Each year, four irrigations were applied.

Plant protection and weed management: Pesticide was used for the protection against major and minor pest. Insecticide (Dichloroves @ 1.5 l/ha) and Fungicide (Copper oxychloride @ 1 kg/ha) were applied at the time of disease and pest infestation. Weed management was done manually only in unmulched control (UM) plots.

Measurement of soil properties

Field method-Soil moisture and temperature: Soil moisture contents were determined gravimetrically in all the plots at 0-15 cm depth at 15 days interval during the period of experimentation. Likewise, soil temperature in mulched plots and unmulched control plot at 15 cm depth was recorded at 7:30 and 14:30 hours on alternate days throughout the period of experimentation using digital soil thermometer (model CT-802).

Laboratory method

Soil sampling and analyses: Three representative soil samples from 0-15 cm depth were collected before transplanting and after crop harvest for analysis of physical and chemical properties following standard procedures. Soil bulk density of the surface layer (0-15 cm) was determined using the core method (Blake, 1986). In the laboratory, sample of bulk density were carefully trimmed and dried at 105 ˚C to a constant weight.

$$\text{Bulk density (Mg/m}^3\text{)} = \frac{\text{Oven dry weight of soil}}{\text{Volume of core}} \quad (1)$$

The water holding capacity was determined by means of Keen's Raczkowski box method as described by Piper (1950).

$$\text{Water holding capacity (\%)} = \frac{\text{Maximum water absorbed by the soil}}{\text{Oven dry weight of the soil}} \times 100 \quad (2)$$

Soil moisture retention was measured by pressure plate apparatus as suggested by Richards (1947). The pH of soil was measured with the help of a pH meter, maintaining the soil-water ratio of 1:2.5 as described by Jackson (1973). The organic carbon content in soil samples was estimated by Walkely and Black (1934) method as suggested by Jackson (1973). Available soil S was estimated by 0.15% $CaCl_2$ solutions as per method suggested by Williams and Steinbergs (1959) and described as turbidimetric method given by Chesnin and Yein (1951). Exchangeable Ca and Mg were analysed after extraction of soil with neutral normal 1N NH_4OAc (pH 7.0) using Atomic Absorption Spectrophotometer as suggested by Tondon (2005).

Yield attributes, yield and quality: Length of stalk was measured in centimetres from the point of uppermost secondary root level to the point of first lower leaf. During harvesting, above ground parts of ten randomly selected plants were collected from each treatment for foliage weight. These were air dried, weighed (kg/plot) and converted into tonnes per hectare (t/ha). Curd yield (t/ha) including the stalk at marketable maturity was recorded during harvesting. Longitudinally cut curd was measured in centimetres for equatorial and polar diameter. Curd compactness was determined as per the formula suggested by Pearson (1931).

$$Z = C/W^3 \times 100 \quad (3)$$

Where, Z = Index of compactness; C = Weight of curd in gram; W = Average of polar and equatorial diameter

The values of Z varied from 25-35 g/cm^3; if Z value > 35 g/cm^3 the curd compactness categorised as *compact,* if Z value varied from 25-35 g/cm^3 the curd compactness categorised as *semi compact*, if Z value < 25 g/cm^3 the curd compactness fall under *loose*.

Economic analysis: The benefit-cost ratio was calculated by considering the variable as well as fixed inputs and prevailing market rates, the expenditure incurred on various inputs and operations (Table 2). The fixed cost includes tillage, seed, transplanting, irrigation, pesticide, harvesting and transportation. Similarly variable cost included Farm yard manures, fertilizer, mulch materials and weeding. The cost of human labour used for tillage, seeding, irrigation, fertilizer and pesticide application, weeding and harvesting of crops was based on person-days per hectare. Simultaneously, gross returns were worked out for each treatment based on quality and market prices of the produce. The net returns were worked out by deducting the cost incurred from the gross return of the particular treatment. Benefit cost (B: C) ratio was calculated by dividing the net return by total cost of production.

Table 2. Cost of key inputs and outputs used for economical analysis during experimentations (2009-11).

Fixed inputs	Fixed cost (INR/ha)
Preparatory tillage	8600.0
Seeds and transplanting	7000.0
Irrigations	6000.0
Plant protection	6900.0
Harvesting, grading, pacing and loading cost	4500.0
Transportation cost of local market (Within 50 km range)	5000.0
Miscellaneous cost	2000.0
Variable inputs	**Variable cost (INR/unit)**
Farm yard manures	1.2/kg
Calcium ammonium nitrate	6.4/kg
Single superphosphate	4.6/kg
Muriate of potash	4.2/kg
Black plastic mulch of 100 micron thickness	160.0/kg
Grass mulch @ 10 t/ha (Air dry)	6000.0/t
Pine needles mulch @ 10 t/ha (Air dry)	6000.0/t
Labour wage for application of mulches (10 labours)	150.0/day
Cost of weeding (106 labours)	150.0/day
Market selling price of produce (Based on compactness)	10-15/kg
INR/US$ exchange rate (Average of 2010 and 2011)	46.0

INR, Indian rupees

Nutrient uptake: The nutrient uptake by the crop was calculated by multiplying the nutrient content with dry matter yield. The nutrient content in grain and straw were determined as per the standard procedure (Tondon, 2005).

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content (\%)} \times \text{dry matter (kg/ha)}}{100} \quad (4)$$

Statistical analysis: The data generated from present investigation were subjected to statistical analysis using the statistical package SPSS 13.0 software (Analyse - General Linear Model-Univariate) (SPSS Inc., Chicago, USA). The same letters with table value represent statistically identical values of the examined combinations of mulching & nutrient levels practices according to Tukey's HSD test determining the least significant difference (LSD) at 5% for testing the significant difference among the treatment means. Regression coefficient between obtained variables was determined using Microsoft Excel.

RESULTS AND DISCUSSION

***In situ* moisture conservation and moisture retention:** Comparatively higher moisture contents under all mulching treatments (Figure 1, 2 and 3) as compared to unmulched control (UM) were observed, those may have been due to the shading effect, which prevented evaporation of moisture from soil surface and reduced vapour diffusion to the atmosphere (Kumar and Dey, 2011). Among different mulches, comparatively the highest moisture contents (44.7%) under the treatment of black plastic mulch (BP) may be due to efficient weed control. Secondly, fact that water after evaporation condenses on the bottom side of the polythene sheet and drips down again on the soil surface. Singh *et al*. (2004) have also reported higher moisture content under black plastic mulch (BP) as compared to unmulched control (UM). Similarly, organic mulches *viz*., pine needle mulch (PN) and grass mulch (GM) also maintained higher moisture content (Figure 1, 2 and 3) which ranged between 27.5% and 37.2% with an average value of 32.3% than that of unmulched control (UM) which was probably due to shading effect.

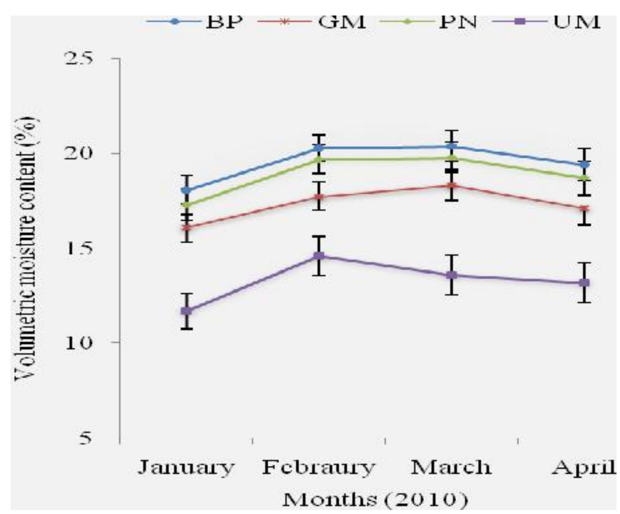

Figure 1. Mean monthly volumetric soil moisture contents under mulch treatments in 0-15 cm depth during 2010. Vertical bars indicate ± S.E. of mean of the observed values.

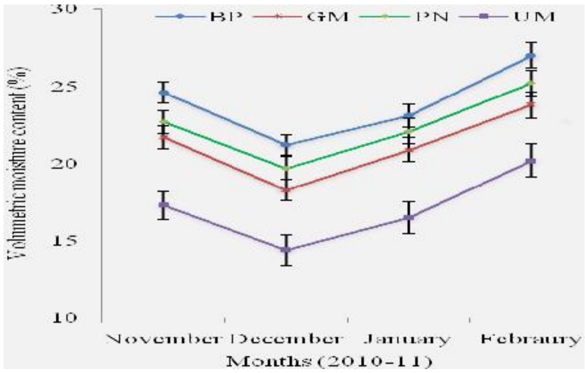

Figure 2. Mean monthly volumetric soil moisture content under mulch treatments in 0-15 cm depth during 2010-11. Vertical bars indicate ± S.E. of mean of the observed values.

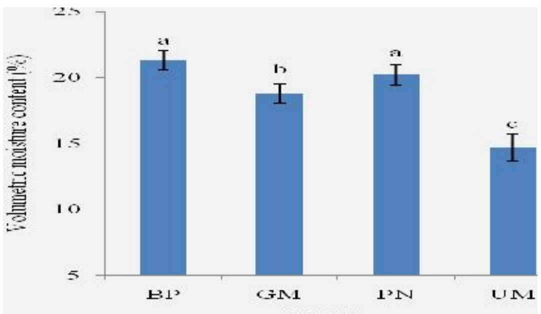

Figure 3. Effect of mulches on volumetric moisture content (%) in 0-15 cm soil depth (average of two years). Vertical bars indicate ± S.E. of mean of the observed values. Different letters indicate significant difference (at 5% level) between the means.

BP: Black plastic mulch, GM: Grass mulch, PN: Pine needles mulch, UM: Unmulched control

Similarly, mulch treatments retained higher moisture content at lower suction (Table 3). This may be due to increase in macro porosity due to enhanced activity of soil micro flora and fauna under organic mulches and the cushioning effect against falling rain drops which reduces surface sealing of surface pores. At higher suction (> 0.33 bar), there was no noticeable difference in water retention under different mulches. This may be due to the reason that at higher suction, water is retained only by the micro pores which are least affected by external forces of disruption.

Soil temperature: Soil temperature was favourably moderated by mulch treatments during both the years (Figure 4 and 5) as compared to unmulched control (UM) at 15 cm soil depth. The treatment of black plastic mulch (BP) recorded the highest minimum soil temperature recorded at 7:30 hrs, in comparison with other treatments. On the other hand, it also increased the maximum temperature (14:30 hrs) but not appreciably in both the year of study. The reason that black plastic mulch raised the minimum soil temperature but had a little effect on maximum soil temperature may be due to the fact that black plastic mulch absorbs much of the incident radiation but transmits less energy to soil because of the presence of bad conductor heat wave, in between black plastic mulch and the soil surface which does not favour increase in soil temperature, which is in agreement with the findings of Sharma and Kathiravan (2009).

Table 3. Effect of mulches on moisture retention at the end of experiment in 0-15 cm soil depth.

Suctions (Bar)	Initial value	Treatments			
		UM	BP	GM	PN
0.33	19.8	19.7	21.1	22.9	21.5
0.50	19.2	18.8	19.6	20.5	20.2
1	18.1	17.5	17.7	17.8	17.2
5	14.7	13.4	14.8	14.1	13.8
10	9.2	9.1	8.9	10.7	10.5
15	8.1	7.6	7.4	7.1	6.9

BP: Black plastic mulch, GM: Grass mulch, PN: Pine needles mulch, UM: Unmulched control

The treatments of organic mulches such as grass mulch (GM) and pine needles mulch (PN) also raised the minimum soil temperature during both the years at 15 cm soil depth. This may be due to the reducing negative heat flux and an increase in diffusion path of heat transfer from mulching material into the surface. The increase in minimum soil temperature can be attributed to the insulating effect of the straw mulch which reduces the negative heat flux to the atmosphere. Sharma and Kathiravan (2009) also registered a trend similar to that recorded in the present investigation for the soil temperature under mulch and no mulch conditions.

However, maximum soil temperature (14:30 hrs) decreased under both GM and PN mulch treatments during both the years of investigation, which could be ascribed to higher albedo value of these mulches. Though the albedo values of grass mulch and pine needles mulch were not determined but pine needles mulch might have lower albedo value than grass mulch because of its dark brown colour. Thus, the differential behavior of GM and PN in lowering the maximum soil temperature could be ascribed to their difference in albedo value and also that these mulches have the ability to reduce both positive and negative heat flux into and out of soil and thus decrease the extremes of diurnal temperature fluctuations and increase the lower temperature (Kumar and Dey, 2011).

Bulk density and organic carbon: The reduction in bulk density (2.4%) under PN and GM in surface soil (0-15 cm) in Table 4 might be due to the loosening of soil due to decomposition of organic mulches resulting in top soil becoming more friable. Other possible reason that accumulation of decomposed and partially soil organic carbon enriched materials trigger microbial processes that enhance soil resilience as compared to the unmulched treatment. Bulk density increased under unmulched treatment may be due to compaction of surface soil which had a deleterious effect on crop growth. This effect might have been mitigated under mulch treatments.

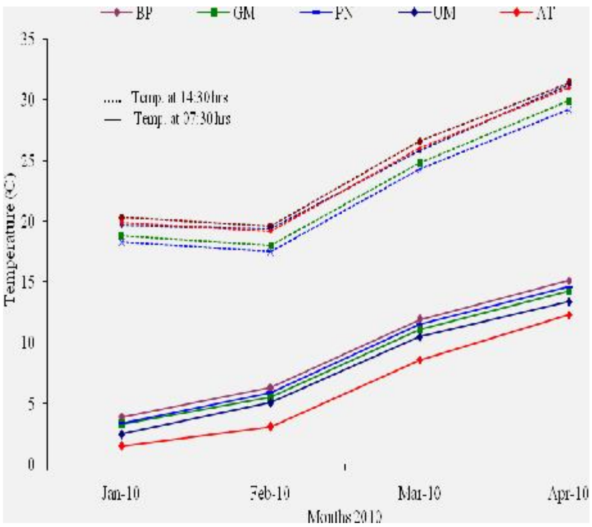

Figure 4. Mean monthly soil temperature at 15 cm soil depth under mulch treatments during 2010

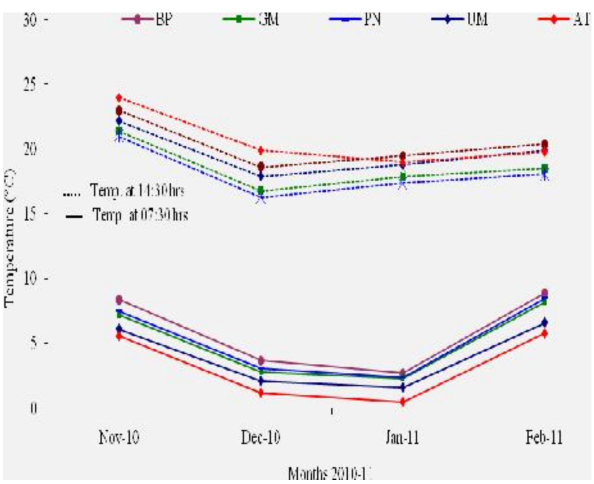

Figure 5. Mean monthly soil temperature at 15 cm soil depth under mulch treatments during 2010-11

BP: Black plastic mulch, GM: Grass mulch, PN: Pine needles mulch, UM: Unmulched control, AT: Air temperature

Organic mulches *viz*., grass mulch (GM) and pine needle mulch (PN) enhanced the organic carbon which ranged between 19.5% and 24.4% with an average value of 21.8% (Table 4) over unmulched control (UM) due to the fact that organic mulches upon decomposition provide carbonaceous material to the soil. The increased soil organic carbon is especially important to crop development since it may have a direct effect on soil bulk density. The present findings are in close conformity with those reported by Stockdale *et al*. 2002, and Scharenbroch and Lloyd, 2006.

Availability of secondary nutrients (S, Ca & Mg): This two years study shows that application of mulches, different levels of nutrients alone and their interaction were well reflected to more conducive for availability of secondary macro nutrients (Table 4 and 5) due better hydrothermal regime and produced more carbonaceous material through decomposition of organic mulches, root biomass and above ground biomass, and also lesser weed biomass. The favourable effect of mulches on increasing the available plant nutrient content in the soil is well documented by Sinkeviciene *et al*. 2009. The enhancement in the concentration of calcium and sulphur in higher levels of NPK obviously may also be due to higher nutrient levels supplied through calcium ammonium nitrate (CAN) and single superphosphate (SSP) fertilizers, respectively which might have resulted in an increase in the concentration of nutrient elements under higher nutrient levels, and positive effect in combination of mulches and nutrient levels (Nedunchezhiyan, 2010).

Yield attributes, yield and quality: The higher yield attributes (stalk length and foliage weight) and curd yield recorded under mulch treatments as compared to unmulched control (Table 6) may be ascribed to favourable hydrothermal regimes and lesser weed population. Cauliflower growth parameters like stalk length (11.7%) and foliage weight (21.9%), and yield (34.6%) have been increased under BP over UM for two major reasons. First, BP mulching reduces soil evaporation by intercepting the steam that is released when water moves from deeper soil layer to the top soil by capillary and second, maintains the stability of the top soil water content, which increases crop transpiration.

Organic mulches (PN and GM) also improved the cauliflower growth (stalk length by 5.9-8.8%, and foliage weight by 7.3-15.1%) and yield (by 16.0% to 21.4%) over UM (Table 6) for the probable reason that organic mulch conserved relatively higher moisture and better weed suppression (Ahmed *et al.* 2014), and also organic mulch upon decomposition releases nutrients and organic matter (humus) resulting in increased growth of the plants. Humus materials are composed of mineral elements, plant hormones, and amino acids that create beneficial conditions for crop yield and anti-stress adaptation (Garcia *et al*. 2014). Also, the fact that mulch covers the soil thereby reducing the rate of removal of water from the soil surface to the atmosphere *i.e*., evaporation, protect the soil and its organic content from

Table 4. Effect of mulches and nutrient levels on soil properties in 0-15 cm depth (average of two years).

Treatment composition	Bulk density (Mg/m^3)	Water holding capacity (%)	pH (1:2.5)	Organic carbon (g/kg)	SO_4^{2-}-S (kg/ha)	Exch. Ca^{2+} (kg/ha)	Exch. Mg^{2+} (kg/ha)
Mulches							
BP	1.27^a	45.5^a	6.97^a	8.3^a	66.3^c	701.6^c	430.1^a
GM	1.25^b	45.9^a	6.87^a	10.2^b	63.2^b	698.2^b	429.3^a
PN	1.25^b	45.8^a	6.81^a	9.8^b	64.7^{bc}	699.8^{bc}	429.7^a
UM	1.28^a	45.2^a	6.91^a	8.2^a	55.5^a	694.5^a	427.3^a
LSD $_{(P=0.05)}$	0.02	NS	NS	0.42	3.25	4.83	NS
Nutrient levels							
N_1	1.26^a	45.7^a	6.90^a	9.3^a	65.5^b	704.4^b	431.0^a
N_2	1.26^a	45.6^a	6.90a	9.2^a	63.7^b	702.8^b	430.6^a
N_3	1.27^a	45.4^a	6.87^a	8.9^a	58.1^a	688.4^a	426.0^a
LSD $_{(P=0.05)}$	NS	NS	NS	NS	2.20	4.19	NS

direct contact with warm air thus increasing soil microbial activity and consequently encouraging decomposition may contribute to higher growth and yield of cauliflower grown in mulched soils. The present findings are in close conformity with those reported by Awasthi *et al*. (2006), and Vazquez *et al*. (2010).

Comparison of data among different nutrient levels (Table 6) revealed improvement in stalk length (by 5.7%), foliage weight (by 41.9-44.3%), and yield (37.8-42.0%) were with the application of N_1 and N_2 levels of nutrient over N_3. These results are in close conformity with the findings of Liasu and Achakzai (2007), and Vazquez *et al*. (2010). The application of NPK fertilizers supplemented the nutrients content of the soil by making available essential nutrient elements required for improved nutrition and healthy growth of the plant. Combination of mulch and nutrient levels (Table 7) also improved the growth and yield of cauliflower which might be due to better utilization of applied nutrients owing to adequate moisture availability in rainfed areas, Another possible reason for higher growth and yield in N_1 and N_2 treatments are the better management practices and residual effect of fertilizer from basal and top dressing in second year of experimentation (2010-2011).

Combination of mulch with NPK nutrients provided additional nutrients and humic materials from decaying mulch which increased the nutrient retention capacity of the soil and thereby provided sustained source of macro and micro nutrients for increased growth and yield of cauliflower thus resulted in increased growth and yield of cauliflower. The treatment combinations of BPN_1 and BPN_2 had recorded significantly higher yield with an average value of 26.3 t/ha as compared to rest of the treatment combinations. The combinations of organic mulch and two levels of nutrients *i.e*., 125% and 100% NPK were statistically equal to each other. Beneficial effects of mulches and nutrient levels on crop growth and yield due to the interactive effect of mulches and nutrient level could be ascribed to the additive effect of all the inputs on the availability of different nutrients to the plants. These results get support from the findings of Nedunchezhiyan (2010), and Vazquez *et al*. (2010).

Quality of cauliflower *i.e*., curd compactness is an important parameter that determines the marketable value of the produce as loose filling of the curd fails to maintain a proper curd shape. All the mulching treatments had improved the curd compactness over unmulched control by 15.9-21.7%; this may be due to modifying effects on soil hydrothermal regimes and considerable control on weed population. Irrespective of the different nutrient levels (Table 6), the curd compactness was increased with nutrient levels, while, application of 125% (N_1) and 100% (N_2) of NPK were produced almost statistically similar compactness (6.3-8.2%) as compared to below recommended dose of nutrients (75% NPK: N_3). The treatment combination BPF_1 resulted in 30.0 per cent higher curd compactness over UMF_3 (32.0 g/cm^3). Improved curd compactness of cauliflower due to interactive and complementary effect of mulches and nutrient level (Table 7) might be ascribed to the additive effect of all the inputs on the availability of nutrients to the plants. Several workers reported that improvement in compactness of cauliflower might be due to better curd size, plant height, more photosynthetic area, better accumulation of food deposits in edible parts which resulted in higher compact curd (Shelke *et al*. 2001).

Economical profitability: The positive effects of mulches and nutrient levels on yield (Table 6) were well reflected into more favourable economics for cauliflower production. The cost of cauliflower production under BP was higher (63.5%) as compared to UM because of higher cost involved in black plastic mulch. Organic mulch such as GM and PN had maintained the same cost of production (49.7%) due to same cost involved in purchasing and their placement in field. UM plots recorded lower cost of production (1995.7 US$/ha) than in mulched plots. Among the nutrient levels (Table 6), the higher cost of production was recorded with the application of 125% (N_1) and 100% (N_2) of NPK fertilizer as compared to 75% NPK fertilizer (N_3). While comparing different combinations of mulch and nutrient levels (Table 7), it appeared that BP along with levels of nutrients recorded the highest cost of production and was higher by 16.0-16.4% compared to the combinations of UM and nutrient levels.

The net return (Table 6) of cauliflower was increased by 105.5%, 79.5% and 65.9% under BP, PN and GM, respectively as compared to UM (2184.3 US$/ha). In comparison of nutrient levels, the treatments N_1 and N_2 incurred almost similar significantly higher net return (25.7-27.6%) as compared to lower dose of fertilizer *i.e.*, 75% of NPK fertilizer. The treatment combination (Table 7) of black plastic mulch and 125% nutrient level (BPN_1) registered the highest increment in net return (5404.3 US$/ha) which was at par with black plastic mulch and 100% nutrient level (BPN_2). The seasonal income in term of benefit cost (B: C ratio) ratio was the highest with the application of BP which was followed by PN, GM and UM. In two years of study, the trend of B: C ratio was: BP > PN > GM > UM. Higher and recommended dose of nutrients (*i.e.*, 125% and 100 NPK, respectively) were statistically at par with each other in respect of profitability therefore, there is no need of extra application of nutrients. On the basis of benefit cost ratio, recommended dose of nutrients was the best for cauliflower production. Mulching and fertilizer application together significantly promoted the profitability of cauliflower in mid hills of Himachal Pradesh due to additional yield (Table 7). Combinations of mulches and nutrient levels comprehensively improved the benefit cost ratio by 2.3, 2.2, 2.2, 2.1, 2.0 and 2.0 times in treatments BPN_1, BPN_2, PNN_1, PNN_2, GMN_1 and GMN_2, respectively, compared to unmulched control with 75% nutrient level (UMN_3). The benefit comes mainly due to higher and better quality of crop produce, efficient weed control and higher nutrient availabilities (data not shown). These findings are in agreement with the results reported by Singh *et al*. (2004), and Nedunchezhiyan (2010) who also recorded higher net returns under black plastic mulch.

Uptake of secondary macro nutrients (S, Ca & Mg): Application of mulches and nutrient levels individually or together improved available soil sulphur, calcium and magnesium as compared to unmulched control alone (Table 6). Due to accumulation of secondary macro nutrients under mulches like, BP, GM and PN which ultimately enhanced the uptake of S, Ca and Mg by 6.9-22.4% over unmulched control (UM) because of mulching has an ability to reduce leaching of nutrients in the soil profile and also increase in the cation exchange capacity of soil. The efficient utilization of nutrients under mulches treatments could be expected because of an enlarged, more fibrous and more active root system, conditioned by relatively better moisture and thermal regimes, which enhanced root growth, thus, increased the potential for higher nutrient uptake (Kumar and Dey, 2011). Mulching with higher levels of nutrients application (Table 7) resulted in higher nutrient status which the crops utilized efficiently and produced higher yield that led to higher nutrient uptake in these treatments. The higher uptake of secondary nutrients in organic mulches with higher rates of nutrients application might have been due to higher moisture regimes maintained, which in turn allowed greater proliferation of roots, thereby facilitating higher absorption of nutrients and water from the soil.

Table 5. Interaction effect of mulches and nutrient levels on soil properties in 0-15 cm depth (average of two years).

Treatment composition	Bulk density (Mg/m^3)	Water holding capacity (%)	pH (1:2.5)	Organic carbon (g/kg)	SO_4^{2-}-S (kg/ha)	Exch. Ca^{2+} (kg/ha)	Exch. Mg^{2+} (kg/ha)
BPN_1	1.27^a	45.7^a	6.99^a	8.5^a	69.5^f	708.6^c	432.2^a
BPN_2	1.27^a	45.5^a	6.98^a	8.3^a	67.7^{ef}	706.4^{bc}	431.8^a
BPN_3	1.29^a	45.3^a	6.94^a	8.1^a	61.7^{cd}	689.8^a	427.0^a
GMN_1	1.24^a	46.1^a	6.89^a	10.4^a	66.6^{ef}	703.8^{bc}	431.5^a
GMN_2	1.25^a	45.9^a	6.88^a	10.3^a	64.6^{de}	702.5^{bc}	431.1^a
GMN_3	1.26^a	45.7^a	6.84^a	9.9^a	58.2^{bc}	688.4^a	425.7^a
PNN_1	1.26^a	45.9^a	6.82^a	10.0^a	68.2^{ef}	706.2^{bc}	431.9^a
PNN_2	1.26^a	45.9^a	6.82^a	9.9^a	66.0^{def}	704.2^{bc}	431.5^a
PNN_3	1.25^a	45.6^a	6.80^a	9.5^a	60.0^{bc}	689.1^a	426.3^a
UMN_1	1.28^a	45.3^a	6.92^a	8.4^a	57.8^{bc}	698.9^b	428.4^a
UMN_2	1.28^a	45.2^a	6.91^a	8.3^a	56.4^{ab}	698.3^b	428.0^a
UMN_3	1.28^a	45.2^a	6.89^a	7.9^a	52.4^a	686.4^a	425.2^a
LSD $_{(P=0.05)}$	NS	NS	NS	NS	4.41	8.37	NS

NS: not significant; BP: Black plastic mulch, GM: Grass mulch, PN: Pine needles mulch, UM: Unmulched control; N_1: 125% of recommended dose of NPK, N_2: Recommended dose of NPK, N_3: 75% of recommended dose of NPK; Different letters in a column indicate significant difference (at 5% level) between the means according to Tukey's HSD test.

Table 6. Effect of mulches and nutrient levels on yield attributes, yield, quality, economics and uptake of secondary nutrients (average of two years).

Treatment composition	Stalk length (cm)	Equatorial diameter (cm)	Polar diameter (cm)	Foliage weight (t/ha)	Curd yield (t/ha)	Curd compactness (g/cm^3)	Cost of production /ha ($)	Net return /ha ($)	B : C ratio	Nutrient uptake (kg/ha)		
										SO_4^{2-}-S	Ca^{2+}	Mg^{2+}
Mulches												
BP	3.8^{c}	16.4^{a}	7.7^{a}	2.34^{c}	23.1^{c}	39.8^{b}	3263.7^{c}	4488.5^{d}	1.37^{d}	7.1^{c}	59.4^{c}	15.8^{d}
GM	3.6^{b}	14.8^{a}	8.4^{a}	2.06^{ab}	19.9^{b}	38.7^{b}	2987.0^{b}	3623.9^{b}	1.21^{b}	6.2^{a}	52.3^{b}	13.9^{b}
PN	3.7^{b}	15.6^{a}	7.7^{a}	2.21^{bc}	20.8^{b}	39.5^{b}	2987.0^{b}	3920.6^{c}	1.31^{c}	6.7^{c}	56.1^{c}	14.9^{c}
UM	3.4^{a}	15.3^{a}	8.0^{a}	1.92^{a}	17.2^{a}	32.7^{a}	1995.7^{a}	2184.3^{a}	1.09^{a}	5.8^{a}	48.6^{a}	12.9^{a}
LSD $_{(P=0.05)}$	0.11	NS	NS	0.16	0.92	1.4	148.6	250.4	0.05	0.42	3.45	0.62
Nutrient levels												
N_1	3.7^{b}	16.3^{a}	7.7^{a}	2.41^{c}	23.2^{b}	39.4^{b}	2840.4^{c}	4300.9^{b}	1.49^{b}	7.3^{b}	61.3^{b}	16.3^{b}
N_2	3.7^{b}	16.0^{a}	7.7^{a}	2.37^{b}	22.5^{b}	38.7^{b}	2808.3^{b}	4120.8^{b}	1.45^{b}	7.2^{b}	60.1^{b}	16.0^{b}
N_3	3.5^{a}	14.2^{a}	7.6^{a}	1.67^{a}	16.3^{a}	36.4^{a}	2776.3^{a}	2241.4^{a}	0.80^{a}	5.1^{a}	42.5^{a}	11.3^{a}
LSD $_{(P=0.05)}$	0.1	NS	NS	0.14	0.8	1.21	5.9	180.8	0.08	0.36	2.99	0.54

NS: not significant; BP: Black plastic mulch, GM: Grass mulch, PN: Pine needles mulch, UM: Unmulched control; N_1: 125% of recommended dose of NPK, N_2: Recommended dose of NPK, N_3: 75 % of recommended dose of NPK; Different letters in a column indicate significant difference (at 5% level) between the means according to Tukey's HSD test.

Table 7. Interaction effect of mulches and nutrient levels on crop performances, economics and uptake of secondary nutrients (average of two years).

Treatment Composition	Stalk length (cm)	Equatorial diameter (cm)	Polar diameter (cm)	Foliage weight (t/ha)	Curd yield (t/ha)	Curd compactness (g/cm^3)	Cost of production /ha ($)	Net return /ha ($)	B : C ratio	Nutrient uptake (kg/ha)		
										SO_4^{2-}—S	Ca^{2+}	Mg^{2+}
BPN_1	3.9^{f}	17.2^{a}	7.7a	2.61^{h}	26.7^{f}	41.6^{e}	3295.7^{b}	5404.3^{p}	1.64^{g}	7.9^{f}	66.3^{g}	17.6^{p}
BPN_2	3.9^{f}	17.1^{a}	7.7a	2.56^{gh}	26.0^{f}	41.0^{de}	3263.7^{b}	5201.6^{p}	1.59^{fg}	7.7^{ef}	64.9^{fg}	17.3^{hp}
BPN_3	3.7^{de}	15.0^{a}	7.6a	1.98^{cd}	18.7^{c}	38.9^{bcd}	3231.6^{b}	2859.7^{cd}	0.88^{c}	6.0^{c}	50.3^{c}	13.4^{c}
GMN_1	3.7^{de}	15.2^{a}	8.6a	2.37^{efgh}	22.8^{de}	40.5^{de}	3019.1^{c}	4409.2^{ef}	1.46^{e}	7.2^{def}	60.2^{def}	16.0^{fg}
GMN_2	3.6^{cd}	15.2^{a}	8.6a	2.32^{efg}	22.2^{d}	39.5^{cde}	2987.0^{c}	4265.2^{de}	1.43^{e}	7.0^{de}	58.9^{de}	15.7^{ef}
GMN_3	3.6^{cd}	13.9^{a}	7.9a	1.55^{ab}	15.8^{b}	37.0^{b}	2954.9^{c}	2197.3^{b}	0.74^{ab}	4.7^{ab}	39.2^{ab}	10.4^{a}
PNN_1	3.8^{ef}	16.3^{a}	7.9a	2.48^{fgh}	24.0^{e}	41.0^{de}	3019.1^{c}	4790.7^{f}	1.59^{f}	7.5^{ef}	63.0^{efg}	16.8^{ghp}
PNN_2	3.8^{ef}	15.8^{a}	8.1a	2.45^{fgh}	22.9^{de}	40.7^{de}	2987.0^{c}	4480.4^{ef}	1.50^{ef}	7.4^{ef}	62.1^{efg}	16.5^{fgh}
PNN_3	3.6^{cd}	14.8^{a}	7.2a	1.73^{bc}	16.7^{b}	37.6^{bc}	2954.9^{c}	2490.7^{bc}	0.84^{bc}	5.2b	43.9^{b}	11.7^{b}
UMN_1	3.4^{b}	16.7^{a}	7.3a	2.20^{def}	19.4^{c}	34.0^{a}	2027.8^{a}	2599.4^{bc}	1.28^{d}	6.6^{cd}	55.8^{cd}	14.8^{de}
UMN_2	3.5^{bc}	16.0^{a}	7.9a	2.15^{de}	19.0^{c}	33.3^{a}	1995.7^{a}	2535.8^{bc}	1.27^{d}	6.5^{cd}	54.6^{cd}	14.5^{d}
UMN_3	3.2^{a}	13.1^{a}	8.9a	1.44^{a}	14.1^{a}	32.0^{a}	1963.6^{a}	1417.7^{a}	0.72^{a}	4.4^{a}	36.6^{a}	9.70^{a}
LSD $_{(P=0.05)}$	0.20	NS	NS	0.29	1.60	2.42	152.7	402.3	0.12	0.73	5.97	1.10

BP: Black plastic mulch, GM: Grass mulch, PN: Pine needles mulch, UM: Unmulched control; N_1: 125% of recommended dose of NPK, N_2: Recommended dose of NPK, N_3: 75 % of recommended dose of NPK; Different letters in a column indicate significant difference (at 5% level) between the means according to Tukey's HSD test.

Correlation among nutrients and crop performances: In present study, positive correlations were observed between secondary macro nutrient uptake and crop performances like, foliage weight, yield and compactness under mulches conditions as well as nutrient levels (Table 8). This may be due to that cauliflower crop have high sulphur requirements and higher rate of sulphur uptake improved the metabolic activities of vitamins, biotin, thiamine and coenzyme A in plants (Rattan and Goswami, 2009). Calcium plays a role in mitosis (cell division), activates enzymes and facilitates the growth of meristems and functioning of the root tips of plants (Ratan and Goswami, 2009). Magnesium being a constituent of chlorophyll promotes movement of sugar within the plants (Rattan and Goswami, 2009). All these functions of nutrients are helped in improvement of growth yield and quality of cauliflower.

Table 8. Correlation among secondary macro nutrient uptake and foliage weight, curd yield and curd compactness of cauliflower on different mulches and nutrient levels.

Nutrient uptake under mulches	Foliage weight	Curd yield	Curd compactness
SO_4^{2-}—S	1.000*	0.976*	0.843*
Ca	1.000*	0.982*	0.861*
Mg	1.000*	0.983*	0.861*
Nutrient uptake under nutrient levels			
SO_4^{2-}—S	1.000*	0.999*	0.983*
Ca	1.000*	0.999*	0.986*
Mg	1.000*	0.999*	0.985*

*Indicates significant at $P \leq 0.05$.

Conclusion: it may be concluded that mulches are the best means for providing favorable soil environmental conditions for cauliflower growth in mid hills of Himachal Pradesh. Among the mulches, black plastic mulch (BP) conserved the highest moisture contents and regulating soil temperature as compared to pine needles mulch (PN), grass mulch (GM) and unmulched control (UM). The grass and pine needles mulches significantly reduced soil bulk density and increased organic carbon, available soil sulphur and calcium as compared to BP and unmulched control. Improvement in soil properties were well reflected in maximizing growth attributes *viz*., stalk length and foliage weight, and yield of cauliflower in mid hill conditions of Himachal Pradesh. Based on B: C ratio, the treatment of black plastic mulch and 100% recommended dose of NPK was most economical which closely followed by pine needles mulch with 125 % recommended dose of NPK.

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