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Effect of using Agrogeotextiles on soil carbon sequestration in the Indian Himalayas

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ABSTRACT

Agrogeotextiles (AGT) have potential for soil conservation, but limited information is available on effect of AGT on C sequestration and soil aggregation in Indian Himalayan region (IHR). Hence, the study was conducted on a 4% slope at Selakui, Dehradun in a maize-based cropping system where *Arundo donax* mats were used as AGT mats for soil conservation. Soil sampling was done in December 2021 after vegetable pea harvest and results indicated that in 0–15 cm soil depth, Maize + *Arundo donax* mat (10 cm thick) on 0.5 m vertical interval vegetable pea - wheat (M+A10D0.5-V-W) had ~23% higher total soil organic C (TSOC) in bulk soils than the control (M-W) plots. Plots with *Arundo donax* mats exhibited ~12% higher TSOC than plots without the mats. Plots under M+A10D0.5-V-W and maize-vegetable pea-wheat under bench terracing (M-V-W)B showed similar impacts on C sequestration. M+A10D0.5-V-W plots had ~36% greater macroaggregate and ~35% higher mean weight diameter (MWD) than M-W plots in the 0–15 cm soil depth. Microbial biomass C (MBC) enhanced by ~86% under M+A10D0.5-V-W over M-W in the 0–15 cm soil depth due to higher root biomass, root exudates and metabolizable C. Thus, microbial quotient (MQ) was also increased. Mean annual soil loss value of 2020–2021 and 2021–2022 ranged from 0.4 t/ha/yr to 2.9 t/ha/yr which was correlated with carbon management index (CMI) value. The CMI was ~38% higher in M+A10D0.5-V-W plots than M-W due to emplacement of *Arundo donax* mats, resulting in better soil aggregate stability. Thus, AGT application can be a potential practice for soil aggregation stability and C sequestration in the IHR. Conservation soil practices along with AGT are more profitable than conservation soil practices alone which had ~10% less benefit : cost ratio (B:C) on 4% land slopes of IHR.

Keywords: Agrogeotextiles, *Arundo donax*, C sequestration, Carbon management index

A potential method that increases food production and enhances soil quality is soil carbon (C) sequestration, which involves fixing long-lived C pools in soils for the long run (Kundu *et al.* 2014). The conventional intensive tillage operation causes erosion, reduces water infiltration rate and causes a decline in soil organic matter (SOM) (Yadav *et al.* 2017). Recent estimates indicate that the Indian Himalayas may experience soil erosion rates of more than 40 Mg/ha/yr, which is significantly higher than the specified soil loss tolerance level of 10 Mg/ha/yr (Sharma *et al.* 2017). Higher productivity has been attained through conservation agriculture (CA), which involves soil cover through agricultural residues and minimal soil disturbance (Bhattacharyya *et al.* 2012). Agrogeotextiles (AGT) application is an effective practice to reduce soil loss as well as increase C sequestration and is an affordable soil conservation method (Bhattacharyya *et al.* 2010). As an AGT with a rough texture, high water-holding capacity and increased weight when wet, *Arundo donax* ensures physical contact between the soil and geotextile, which helps to reduce soil erosion (Rickson *et al.* 2006). Soil organic carbon (SOC) content is expected to rise as a result of management strategies that ensures more residues are added to soils (Das *et al.* 2018). AGT application in soil reduces soil loss by enhancing aggregate stability as well as C sequestration in soil. Incorporation of legume and crop residue retention can also be a good option to maintain soil quality, reduce soil loss as well as enhance C sequestration in soil. Although many studies have examined about total SOC, soil aggregation, and crop productivity, little information is known about the impact of AGT placement on carbon sequestration, different C fractions, and their impact on aggregate proportion within soil layers in maize (*Zea mays* L.)-based cropping systems in the Indian Himalayan region (IHR). Keeping above in view, the following objectives of

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the present study were carried out: (i) to evaluate the impact of AGT application in the maize crop on carbon pools within different soil depths, (ii) to assess the aggregate stability and Carbon Management Index (CMI) of soil to enhance carbon sequestration and reduce soil loss for two rainfed crops (wheat after vegetable pea) that are also cultivated under conservation tillage.

MATERIALS AND METHODS

The present study was carried out at the experimental field of Selakui, ICAR-Indian Institute of Soil and Water Conservation in Dehradun, Uttarakhand (situated at 30° 20′ 40″ N, 77° 52′ 12″ E 516 m amsl) on a 4% slope on maize-vegetable pea-wheat crop cycle. The plot size is 100 m × 20 m. Randomised block design was used for sampling, which included five replications across four soil depths. Soil loss and yield data of maize, wheat and vegetable pea were collected from 2020–2021 and 2021–2022 as well as soil samples were also collected. The site comprises of mixed hyperthermic typic udorthents with initial *p*H (1:2.5) 4.3, oxidizable soil organic carbon 6.8 g/kg, bulk density 1.36 Mg/m^3, fine sand 458.2 g/kg, silt 336 g/kg, clay 175 g/kg and infiltration rate 0.5 cm/h. Climate in the study area is subtropical. During the rainy, autumn and winter seasons, field experiments were carried out on crops of zero-tilled maize (var. Kanchan), minimum-tilled vegetable pea (var. Arkel) and wheat (var. UP-2572). *Arundo donax* mats were maintained during the maize growing season. After the harvest of the maize, mats were absorbed and mixed in the field. Other crop management details were mentioned by Singh *et al.* (2019). Treatments consist of T$_1$, M-W [Maize – wheat]; T$_2$, M+A5D1-W [Maize + *Arundo donax* mat (5 cm thick) on 1 m vertical interval (VI) – wheat]; T$_3$, M-V-W [Maize - vegetable pea – wheat]; T$_4$, M+A5D1-V-W [Maize + *Arundo donax* mat (5 cm thick) on 1 m VI - vegetable pea – wheat]; T$_5$, M+A10D1-V-W [Maize + *Arundo donax* mat (10 cm thick) on 1 m VI - vegetable pea – wheat]; T$_6$, M+A5D0.5-V-W [Maize + *Arundo donax* mat (5 cm thick) on 0.5 m VI - vegetable pea – wheat]; T$_7$, M+A10D0.5-V-W [Maize + *Arundo donax* mat (10 cm thick) on 0.5 m VI - vegetable pea – wheat] and; T$_8$, (M-V-W)B [Maize - vegetable pea - wheat on bench terraces]. Schematic diagram is mentioned in Fig 1.

The study by Singh *et al.* (2019) provided the values for the initial soil properties. At vegetable pea harvest in December 2021, soil samples from the four soil depth layers (0–5, 5–15, 15–30 and 30–60 cm) were taken from each individual plot in five replications. For simplification, 0–5 and 5–15 cm data were averaged and reported as 0–15 cm data. For aggregate separation, a portion of the soil samples from the 0–15 cm and 15–30 cm soil layers were air-dried, grounded, and sieved to pass through an 8-mm sieve (these samples are referred to as bulk soils). Wet sieving was used to test the aggregate stability of the materials (Cambardella and Elliott 1993). Sieves of 2000, 250, and 53 µm sizes were used. In that case, large macroaggregates (> 2000 µm) and small macroaggregates (250–2000 µm) were regarded as macroaggregates, while microaggregates (53–250 µm) and silt and clay-sized fractions of soil (<53 µm) were considered as smaller macroaggregates. All aggregate fractions were oven dried at 40°C to obtain consistent weight. The following equation (van Bavel 1949) was used to obtain the mean weight diameter (MWD):

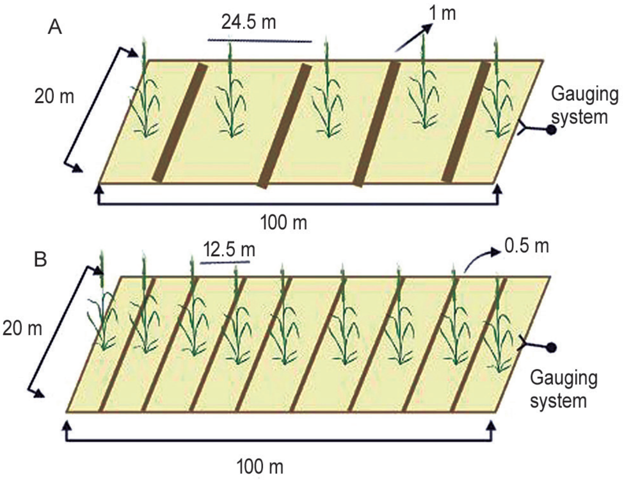

Fig 1 Schematic diagram of field experiment where plot with *Arundo donax* mat (5/10 cm thick) on A, 1 m vertical interval and; B, 0.5 m vertical interval.

$$\text{MWD} = \sum A^*B \quad (1)$$

Where A, average diameter (mm) of the soil aggregate fractions and; B, each aggregate size weight percentage. Total C concentrations in aggregates and bulk soils were measured using a CHN analyzer (Foss Heraeus Elemental Analyzer CHN-ORAPID, anau, Germany). The total soil C measurement was interpreted to be similar to the total SOC because the samples were free of inorganic C (carbonates). Wet oxidation was used to calculate the organic carbon in the soil sample (Walkley and Black 1934). Chemical extractants enable the classification of SOC into labile C, less labile C, and recalcitrant C pools. Following Chan *et al.* (2001), the labile and recalcitrant C pools within bulk soils (0–15 cm, 15–30 cm soil layers) were estimated. Pool I and II constituted labile C and recalcitrant C was contained in pools III and IV (Chan *et al.* 2001, Bhattacharyya *et al.* 2011). The following equation was used to determine oxidisable organic C:

$$\text{Organic C (\%)} = (b\text{-}s) \times 3)/\ b \times \text{weight of soil} \quad (2)$$

Where, b and s are volume (mL) of ferrous ammonium sulphate consumed for blank and soil sample respectively. The permanganate-oxidizable organic C (KMnO$_4$-C) was identified using the method of Tirol-Padre and Ladha (2004). Following the chloroform fumigation extraction procedure, the amount of soil microbial biomass carbon (MBC) was calculated (Jenkinson and Powlson 1976). The ratio of microbial biomass C to SOC was used to calculate the microbial quotient. C management index (CMI) (equation 2) was determined using a formula developed by Blair *et al.*

(1995) based on difference in total organic carbon (TOC) between the control (M-W) and particular treatment.

$$CMI = x \times y \times 100 \qquad (3)$$

Where, x and y represent carbon pool index and the lability index which were calculated using equation (4) and (5).

$$CPI\ (x) = w/v \qquad (4)$$

$$y = m/n \qquad (5)$$

Where, w, TOC of treated plots (g/kg); v, TOC of reference (M-W) (g/kg); m, denotes labile C content (oxidised C by $KMnO_4$-C) (g/kg) and; n, denotes non-labile C content (unoxidized C by $KMnO_4$-C) (g/kg). The soil loss value of the experimental area was calculated using the hydro-graph connected Coshocton wheel method and mean yield data of three different crops were also calculated (Singh *et al.* 2019). The cost of cultivation under various treatments was calculated using market price for various inputs and outputs in Dehradun, Uttarakhand, India. Cost of cultivation included costs of seed, pesticides, mineral fertilisers, AGTs, and human labour and mechanicals used in land preparation, fertiliser application, plant protection, harvesting, and threshing. The benefit:cost (B:C) ratio was calculated by dividing the gross returns obtained from maize, vegetable pea and wheat seeds, based on the minimum support price (MSP) offered by the Government of India, by the total cost of cultivation. SAS (v 9.1) software was used to conduct statistical analyses ($P < 0.05$) to find significant differences between treatment means.

RESULTS AND DISCUSSION

In 0–15 cm and 15–30 cm depths, proportion of silt+clay was less than macro and micro-aggregates. In 0–15 cm depth, plots under M+A10D0.5-V-W had ~36% higher macroaggregates than M-W (Table 1). Application of *Arundo donax* mat increased macroaggregate proportion by ~19% in *Arundo donax* mat emplaced plots compared to without mat application, due to higher aggregate stability. *Arundo donax* reduced soil loss by enhancing aggregate stability and proportion of macroaggregates which increased total SOC concentration in bulk soils. M+A10D0.5-V-W and (M-V-W)B showed similar trend of macro-, micro-aggregates and silt+clay proportion in 0–15 cm and 15–30 cm depths (Table 2). M+A10D0.5-V-W plots had ~35% and ~24% higher mean weight diameter (MWD) than M-W in the 0–15 cm and 15–30 cm soil depths, respectively (Table 1). No-till farming along with legume inclusion in a cropping system enhances soil aggregation through reduced soil disturbance, higher SOM content, and fungi growth that binds the soil particles and microaggregates (Six *et al.* 2000).

In the 0–15 cm and 15–30 cm depths, M+A10D0.5-V-W plots had ~23% and ~20% more total SOC in bulk soils than control (M-W) plots, respectively. *Arundo donax* mats emplaced plots had ~12% higher TSOC than without *Arundo donax* mats. There was no significant difference in TSOC values between M+A10D0.5-V-W and (M-V-W)B treatments. In 0–15 cm soil depth, M+A10D0.5-V-W plots had ~72% more labile C than M-W due to crop residue addition and rhizodeposition that increased readily hydrolysable C input in surface soil (0–15 cm). Legume incorporation increased labile C by ~31% and ~54% compared to control plots in the 0–15 cm and 15–30 cm soil depths. In the 15–30 cm soil layer, the amount of recalcitrant C was ~55% higher than labile C (Fig 2).

In 0–15 cm soil depth, plots under M+A10D0.5-V-W showed ~24% higher Walkley Black C (WBC) than control plots. $KMnO_4$-C ranged from 0.76–1.14 g/kg in the 0–15 cm depth in different treatments. In 0–15 cm and 15–30 cm soil depths, plots under M-W had ~33% and ~37% lower $KMnO_4$-C respectively (Table 2). MBC concentrations ranged from 229.30–739.55 mg/kg across two soil depths. In the 0–15 cm and 15–30 cm depths, M+A10D0.5-V-W plots had ~86% and ~84% higher ($P < 0.05$) MBC concentration than M-W (Table 2). Higher root biomass, root exudates and metabolizable C might be the reason of increased MBC

Table 1 Distribution (%) of macroaggregates, microaggregates, silt + clay and mean weight diameter (MWD) in the 0–15 and 15–30 cm soil layers affected by using agro-geotextile mats in a maize-based cropping system

Treatment	0–15 cm			15–30 cm			MWD (mm)	
	Macro-aggregates	Micro-aggregates	Silt + clay	Macro-aggregates	Micro-aggregates	Silt + clay	0–15 cm	15–30 cm
M-W	39.07 e	43.77 a	16.77 a	61.68 d	37.18 a	1.09 c	0.63 e	0.75 f
M+A5D1-W	45.28 cd	41.82 bc	12.03 d	62.20 d	35.21 a	1.28 c	0.71 cd	0.78 e
M-V-W	43.18 d	42.61 ab	13.85 bc	61.79 d	35.94 a	1.09 c	0.68 d	0.76 f
M+A5D1-V-W	46.00 c	40.45 c	13.42 bcd	64.84 c	29.96 b	1.32 bc	0.73 c	0.82 d
M+A10D1-V-W	50.26 b	34.42 d	14.31 bc	65.98 bc	29.52 b	1.66 b	0.78 b	0.86 c
M+A5D0.5-V-W	49.82 b	34.52 d	14.72 b	66.82 abc	28.24 bc	1.10 c	0.77 b	0.87 c
M+A10D0.5-V-W	53.24 a	33.60 d	12.80 cd	68.25 a	26.28 c	3.16 a	0.85 a	0.93 a
(M-V-W)B	51.44 ab	33.06 d	14.58 bc	67.77 ab	26.87 c	3.25 a	0.82 a	0.91 b
LSD ($P < 0.05$)	2.727	1.835	1.802	2.008	2.178	0.371	0.033	0.020

Tukey's HSD test indicates that means with lowercase letter within a column are substantially different at $P < 0.05$. Treatment details are given under Materials and Methods.

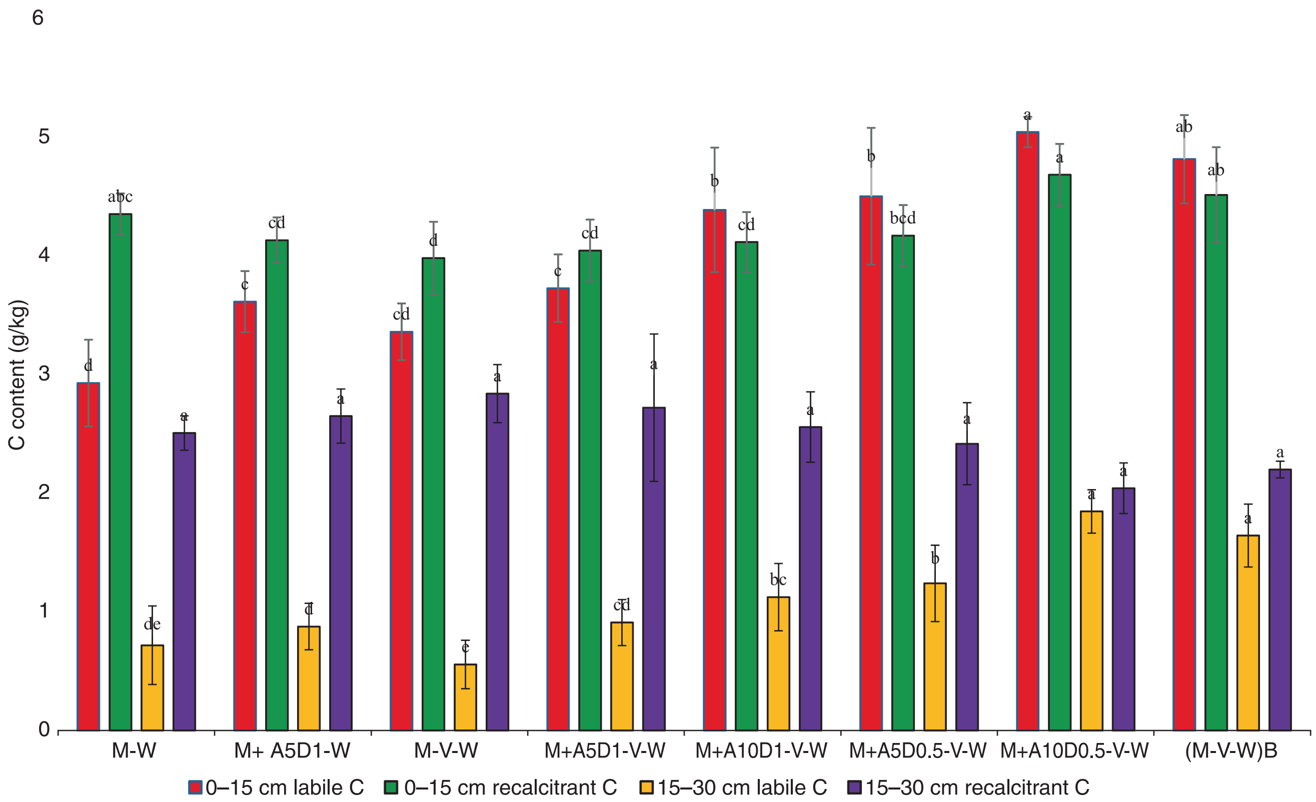

Fig 2 Impacts of different soil conservation practices on soil organic carbon (SOC) pools in bulk soils A, 0–15 cm and; B, 15–30 cm depths in the foothills of the Indian Himalayas.

concentration under M+A10D0.5-V-W compared to control plots. Microbial quotient (MQ) values were significantly different in different treatments in the 0–15 cm and 15–30 cm soil depths. M+A10D0.5-V-W plots had ~51% more MQ value than control (Table 2).

Highest CMI was found in M+A10D0.5-V-W (137.56) having ~38% higher CMI than control plots. *Arundo donax* mat emplaced plots had ~15% higher CMI value than without mats. For every unit increase in CMI, 0.27 unit of soil loss could be restricted at 0–5 cm soil layers (Fig 3). Due to high crop residue retention and emplacement of *Arundo donax* mats decomposition, labile C concentration was increased and soil loss values were reduced as root biomass enhanced soil aggregate stability. Labile C increased lability index of soil, resulting in high C pool index (CPI) and ultimately CMI was increased.

Prices hike in (₹/kg) of maize grain 14.25–19.62; maize straw 1.00; vegetable pea 30–60; wheat grain 18.40–21.25

Table 2 Impacts of different conservation practices on Total organic carbon (TOC), Walkley Black C (WBC), KMnO$_4$-C, Microbial biomass C (MBC) and Microbial quotient (MQ) in the 0–15 cm and 15–30 cm depth in the foothills of the Indian Himalayas

Treatment	0–15 cm					15–30 cm				
	TOC (g/kg)	WBC (g/kg)	KMnO$_4$-C (g/kg)	MBC (mg/kg)	Microbial quotient (MQ)	TOC (g/kg)	WBC (g/kg)	KMnO$_4$-C (g/kg)	MBC (mg/kg)	Microbial quotient (MQ)
M-W	7.81 e	5.69 e	0.76 e	397.97 h	0.051 f	3.28 d	2.38 d	0.40 c	229.30 d	0.071 d
M+A5D1-W	8.13 de	5.97 de	0.88 d	461.09 f	0.057 de	3.54 bcd	2.59 bcd	0.44 bc	269.46 c	0.077 cd
M-V-W	7.95 de	5.81 de	0.87 d	427.33 g	0.054 ef	3.42 cd	2.49 cd	0.42 c	257.38 cd	0.075 cd
M+A5D1-V-W	8.33 d	6.09 d	0.93 cd	502.87 e	0.06 d	3.67 abc	2.67 abc	0.46 bc	306.76 b	0.084 bc
M+A10D1-V-W	8.97 bc	6.59 bc	0.96 c	595.65 d	0.067 c	3.70 abc	2.70 abc	0.49 b	329.84 b	0.09 b
M+A5D0.5-V-W	8.95 c	6.56 c	0.99 bc	621.46 c	0.07 bc	3.77 ab	2.75 ab	0.50 b	340.80 b	0.091 b
M+A10D0.5-V-W	9.57 a	7.05 a	1.14 a	739.55 a	0.077 a	3.92 a	2.86 a	0.63 a	421.54 a	0.107 a
(M-V-W)B	9.36 ab	6.87 ab	1.05 b	692.13 b	0.074 ab	3.84 a	2.80 ab	0.59 a	386.86 a	0.101 a
LSD ($P < 0.05$)	0.407	0.290	0.075	21.416	0.005	0.300	0.228	0.064	37.083	0.010

Tukey's HSD test indicates that means with lowercase letter within a column are substantially different at $P < 0.05$. Treatment details are given under Materials and Methods.

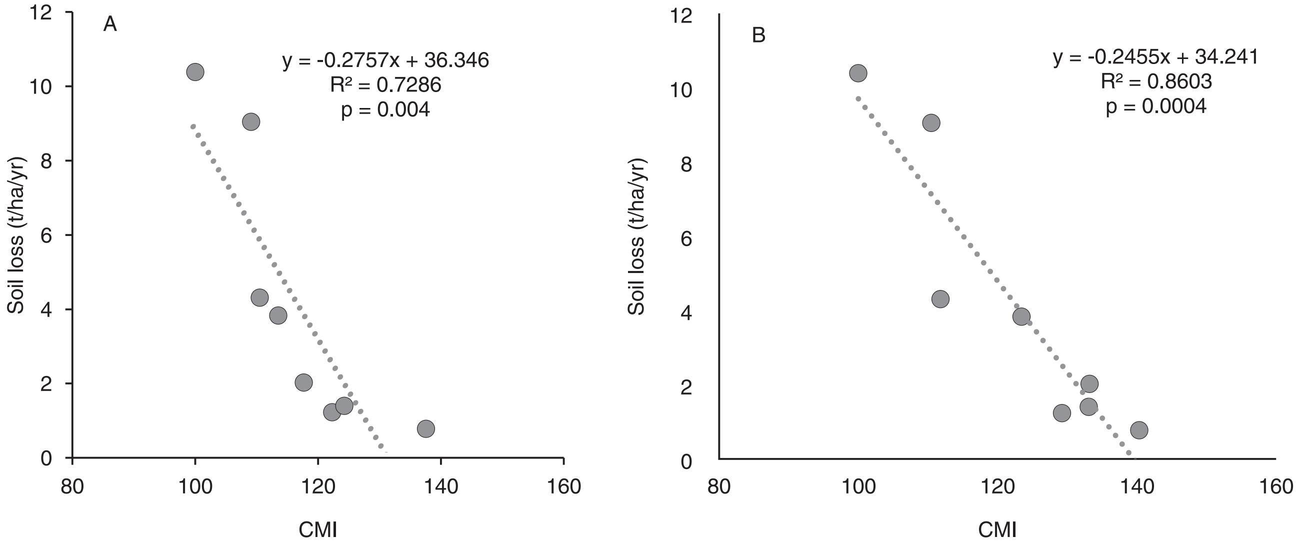

Fig 3 Relation of C management index (CMI) and mean annual soil loss (t/ha/yr) in A, 0–15 cm and; B, 15–30 cm depths as effected by conservation agriculture in the foothills of the Indian Himalayas (n = 8).

Table 3 Mean annual yield data (t/ha/yr) and economics of maize-pea-wheat crop during 2020–2022

Treatment	Maize	Wheat	Vegetable pea	Cost of cultivation (₹/ha)	Benefit:cost ratio
M-W	2.69 c	3.18 bc	-	31450	2.37
M+A5D1-W	3.74 ab	3.49 ab	-	37450	2.48
M-V-W	2.53 c	2.87 c	1.77 c	31450	2.85
M+A5D1-V-W	4.11 a	3.16 bc	1.98 c	37450	2.95
M+A10D1-V-W	4.17 a	3.27 ab	2.18 bc	39450	3.08
M+A5D0.5-V-W	4.52 a	3.58 a	2.49 ab	43450	3.15
M+A10D0.5-V-W	4.61 a	3.50 ab	2.85 a	45000	3.24
(M-V-W)B	2.88 bc	3.27 ab	1.98 c	34450	2.92
LSD ($P < 0.05$)	0.870	0.376	0.488	-	-

Tukey's HSD test indicates that means with lowercase letter within a column are substantially different at $P < 0.05$. Treatment details are given under Materials and Methods.

and; wheat straw 6.0–12.0. Price of *Arundo donax* mat were 5 cm/1 m VI= ₹6,000 ha; 10cm/1 m VI= ₹8,000/ha; 5 cm/0.5 m VI= ₹12,000/ha; 10cm/0.5 m VI= ₹13,550/ha; bench terrace for six years = ₹8,405/ha.

In different treatments, the mean annual soil loss during 2020–2021 and 2021–2022 ranged from 0.4–2.9 t/ha/yr and the values were negatively correlated with CMI values (Fig 3). AGT emplacement had higher C input than without use of AGT, which enhanced soil aggregate stability and C sequestration in soil resulting in increase in mean annual yield ~57%, ~10% and ~26% of maize, wheat and vegetable pea respectively (Table 3). Among all the treatments, the M+A10D0.5-V-W treatment had the highest cost of cultivation followed by M+A5D0.5-V-W and M+A10D1-V-W and the value for M+A10D0.5-V-W treatment was ~43% higher than the M-W (Table 3). The lowest B:C ratio was observed in M-W treatment and the values were ~27% lesser than M+A10D0.5-V-W (Table 3).

From the study, we observed that application of *Arundo donax* mats as AGT could be a potential soil conservation practice to reduce soil loss, enhance C sequestration by increasing soil aggregate stability and ultimately increase crop yields. Due to higher macroaggregate proportion in *Arundo donax* mat-emplaced plots by ~19% compared to plots under without mat application, the application of *Arundo donax* mat raised aggregate stability of soil and M+A10D0.5-V-W plots had ~23% more TSOC and ~72% more labile C than M-W (conventional practice) in 0–15 cm soil depth. CMI was also increased by ~8% due to *Arundo donax* mat emplacement compared to without AGT in surface soil, as *Arundo donax* reduced soil loss by enhancing TSOC, soil aggregate stability and decreased splash erosion. *Arundo donax* mat used plots had 10% higher B:C compared with without mats. Based on B:C ratio as well as C dynamics, M+A10D0.5-V-W should be recommended in 4% land slope of IHR.

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