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Productivity potential of cultivated cereals, pulses, oilseeds, grasses, lemon and conservation of natural resources in grassed waterways in north-western Himalayas

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ABSTRACT

Grassed waterways are developed to serve as safe disposable structures for concentrated runoff, thereby protecting the land against rills and gullies. The studies in beds and side slopes of natural waterway existing at the Research Farm, Selakui, Dehradun were taken up in two phases; in the first phase (2004-2008), three cropping sequences *viz.,* rice bean-gobhi sarson (*Brassica napus*) in first segment (1.0% slope), finger millet-lentil in second segment (1.3% slope) and Guinnea grass in the third segment (1.6% slope) with lemon plantations on side slopes were followed during 2004-2008. In the second phase (2008-2016), cropping sequences of first and second segments were replaced with lemon grass without any changes in intercrops of third segment. The study was conducted with two objectives (1) to assess the productivity levels of traditional cereals, pulses, oilseeds and fodder grasses and horticultural plants (Lemon *cv.* Eureka round), (2) to detain the runoff for longer duration to increase the infiltration opportunity time and retard flow velocities for trapping more sediment in waterway to enhance storage life of farm pond. Subsequent to the reshaping of the waterway in 2004, the productivity levels of finger millet increased from 4.2 q ha^{-1} to 7.6 q ha^{-1}, and of rice bean from 28.2 q ha^{-1} to 49.0 q ha^{-1} during *kharif* season. Similarly, during *rabi* season, lentil productivity ranged from 2.0 q ha^{-1} to 3.7 q ha^{-1} and *B. napus* yield ranged from 3.0 q ha^{-1} to 5.4 q ha^{-1}. Water use for evapo-transpiration demand of *Panicum maximum* was the lowest (145.5 mm) followed by lentil (153.0 mm) and *B. napus* (160.5 mm). Green biomass production of 18.73 t ha^{-1} was recorded in Guinnea grass (third segment). The first segment produced highest average fruit yield of lemon which was 11.26% and 27.78% higher than second and third segments of waterway. There was net deposition of sediment to the tune of 15.41 m^3 and 25.4 m^3 in second and third segments, respectively. Designing and reshaping the waterway, resulted in only 4 overflows from the farm pond in comparison to 10 overflows in previous years.

1. INTRODUCTION

Land degradation signifies a loss or reduction of land productivity as a result of natural or human activity (UNEP, 1993). Land degradation is defined as the reduction of biological productivity and decrease in complexity of terrestrial ecosystem (Lal *et al.,* 2012). Land managers employ runoff harvesting systems for on-site retention of over land flow water. The restoration through vegetation lessens soil erosion and favours on-site deposition of mineral particles and organic residues (Kimiti *et al.,* 2017). Olderman (1991) observed that 1.1 billion ha area is affected by water erosion, and 0.55, 0.24, and 0.08 billion ha by wind, chemical degradation and physical degradation respectively. About 225 M ha of land that is affected by water erosion is degraded to such an extent that it is no longer suitable for agricultural purposes. World's natural resources are declining while their demand is progressively increasing due to rising population.

According to the harmonized database on land degradation in India, 120.72 M ha is subjected to various forms of land degradation with water erosion contributing the most (68.4%) to the total degraded area (Maji, 2007).

About 5334 M t of soil is lost annually, which works out to 16.35 t ha^{-1} (Dhruv Narayan and Ram Babu, 1983). Among different land resource regions, the highest erosion rate was observed in the black soil region (23.7 t ha^{-1} to 112.5 t ha^{-1}) followed by Shiwalik region (80 t ha^{-1}) while the lowest erosion rate was observed in north Himalayan forest region (2.1 t ha^{-1}) (Sharda, 2006). The permissible soil loss tolerance in India has been estimated to vary from 2.5 t ha^{-1} yr^{-1} to 12.5 t $ha^{-1}yr^{-1}$ (Mandal *et al.,* 2011) depending on soil quality and depth. Utilization of natural resources by maintaining or enhancing their qualities for posterity is one of the major goals of current watershed development strategy. Reduction of runoff and soil loss is a fairly good indicator of flood moderation, *in-situ* conservation of rainwater, soil, nutrients and seeds/propagates of natural vegetation for realizing sustained biomass production (Samra and Sharda, 2006). A comprehensive account of restoration of degraded rangelands has been given by Stavi *et al.* (2020). Long-term effect of soil and water conservation (SWC) measures on runoff, sediment and their relationship in an orchard on sloping red soil of southern China was reported by Tu *et al.,* 2018 wherein they showed that SWC measures did not change the rainfall – runoff relationship but did change the runoff – sediment erosion relationship. The erosion reduction mechanism of SWC measures in early phase was the joint function of reducing runoff and changing the runoff sediment relationship, and in the post stable phase it worked mainly by reducing runoff. Grassed waterways are natural or constructed channels established for transport of concentrated flow at safe velocities using adequate vegetation. They are generally broad and shallow by design to move surface water across farmland without causing soil erosion (Fiener and Auerswald, 2017). Vegetative waterway is one of the best low cost techniques to effectively control soil loss and increase infiltration into the soil.

Grassed waterways are used as outlets to prevent rill and gully formation. The vegetative cover slows the water flow, minimizing channel surface erosion. When properly constructed, grassed waterways can safely transport large water flows down slope. These waterways can also be used as outlets for water released from contoured and terraced systems and from diverted channels. This best management practice can reduce sedimentation of nearby water bodies and pollutants in runoff. The vegetation improves the soil aeration and water quality (impacting the aquatic habitat) due to its nutrient removal (nitrogen, phosphorus, herbicides and pesticides) through plant uptake and sorption by soil. The waterways can also provide a wildlife habitat. Introduction of vegetative cover reduces the sediment concentration and increases the water infiltration considerably compared to the control. Mishra *et al.* (2006) studied the effect of slope and vegetative cover on outflow, sediment concentration and deep percolation in channels covered with Bermuda grass, and observed that vegetative cover reduced the sediment concentration and increased water infiltration considerably compared to control. When an interaction between slope and vegetative cover was taken into account, it was preferred to have 25% vegetative cover at the beginning and allow the vegetation to develop to 100% cover in due course.

Sharda *et al*. (2010) assessed production losses due to water erosion in rainfed areas of India. *Kharif* pulses *viz*., rice bean (Jhilangi): *Vigna umbellata*; kidney bean (Chhimi) : *Phaseolus vulgaris,* horse gram (Kulthi): *Dolichos uniflorus* and soybean (Kalibhat) : *Glycine max* are the prominent crops usually grown under mixed cropping with other staple crops like maize and minor millets in the hilly regions of north-western Himalayas. Pulses are known to improve the soil fertility by fixing atmospheric nitrogen and provide effective canopy cover over land, thereby preventing runoff and soil loss in fragile undulating topography of Himalayas. The study aimed to assess productivity and conservation potential of low cost best management practice of grassed water way with respect to cereals, pulses, grasses and lemon cultivated in north-western Himalayas.

2. MATERIALS AND METHODS

The studies were carried out at the research farm Selakui in Dehradun where a natural grassed waterway was existing with 12 terraces (T_1-T_{12}) draining into a farm pond (Fig. 1). The total length of waterway was 1030 m with relief of 12 m draining a cultivated terraced land of 12 ha. The experiment was conducted in two phases, in the first phase (2004-08), waterway beds were under rice bean-gobhi sarson (*Brassica napus*) cropping sequence (first segment, 1.0% slope), finger millet-lentil cropping sequence (second segment, 1.3% slope) and guinnea grass (1.6% slope) in third segment. In the second phase (2008-2016), cropping sequences were replaced with lemon grass in both first and second segments and intercrop remained same in the third segment. Besides production purposes, the vegetative growth of pulses, cereals, and oilseeds in different cropping sequences and grasses in the beds was expected to detain runoff for longer duration for increasing the infiltration opportunity time, and (2) retard flow velocities for trapping more sediment in waterway to enhance storage life of pond, to minimize floods by curtailing overflows from existing farm pond. The objectives were to utilize the existing waterway at the Research Farm Selakui, Dehradun for conserving natural resources and utilizing it for productive purposes in scientifically planned way:

(1) Assessing the productivity potential of rice bean - gobhi sarson and finger millet - lentil cropping sequences in the waterway.

(2) Monitoring the effect of legume-cereal, pulse and oilseed based cropping sequences and the cultivation of grasses towards conservation of natural resources in the unutilized degraded lands of natural waterways.

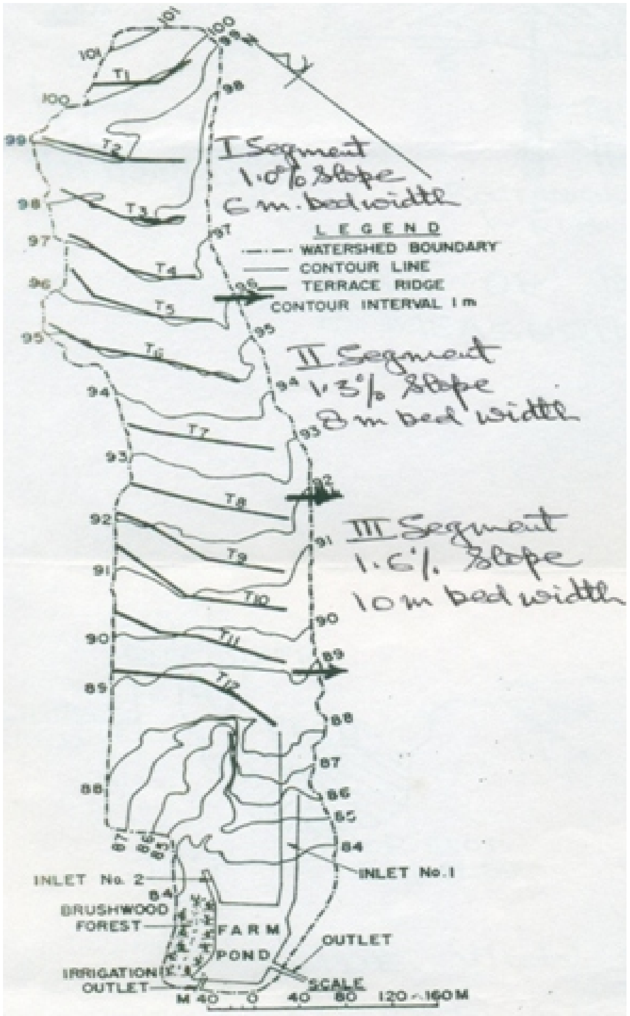

Fig. 1. Farm pond with its catchment at the research farm Selakui

The waterway was reshaped in trapezoidal shape and the bed slopes were reshaped in three redesigned sections having 1.0%, 1.3%, and 1.6% bed slopes where as side slopes of waterway were reshaped as (2:1 and 1.5:1) with 3 variable segments at 4 m vertical interval to carry out gradually increasing volume of runoff (Fig. 2 and Fig. 4).

A local hardy pulse crop of *jhilangi* (rice bean, *Vigna umbellata*) was grown in the first segment (1800 m^2) followed by *ragi* (variety: V.R. – 708) in the second segment (2000 m^2) during *kharif* followed by *gobhi sarson* (*B. napus*) and lentil, respectively during *rabi*. In the third segment, guinea grass (*P. maximum*) was planted in the lowest segment (1900 m^2). On both the sloping sides, 705 plants of lemon (*var.* Eureka round) were planted at 2 m spacing covering 2500 lemon plants per ha. The open space in between the lemon plants was utilized by Bermuda grass (*Cynadon dactylon*) to protect scouring of soil by rain and runoff. The soil in waterway area is acidic, low in nitrogen as well as available potassium, and medium in available phosphorus.

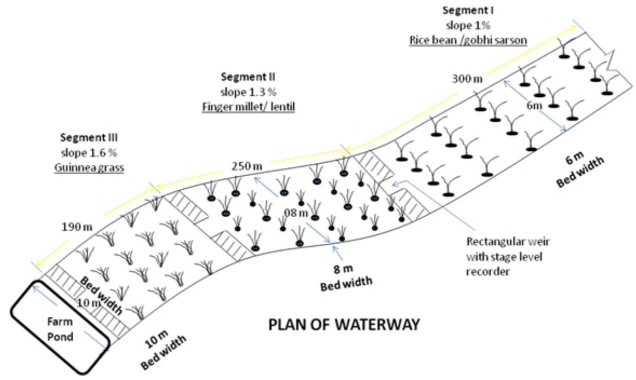

Fig. 2. Diagrammatic view of the reshaped grassed waterway at the Research Farm, Selakui, Dehradun

Agronomic practices: Standard package of practices were followed for raising finger millet and rice bean in sequence. Seed rate of 8.0 and 20.0 kg ha^{-1} was used for finger millet and rice bean, respectively. Similarly the fertilizer doses of 50:40:25 and 20:40:0 (N:P:K) were applied for finger millet and rice bean, respectively. Likewise, fertilizer doses of 0:40:0 and 30:20:40 (N:P:K) were applied for lentil and *Brassica napus,* respectively. The entire dose of P and K was applied as basal dose, except nitrogen which was applied in split doses, one at the time of sowing while the second 30 days after sowing (DAS). The seed rate for lentil and *B. napus* was 40.0 kg ha^{-1} and 2.0 kg ha^{-1}, respectively. Standard package of practice was followed for lemon.

3. RESULTS AND DISCUSSION

Finger millet (*Eleusine coracana* (L.) Gaertn.) is the most important crop among millets having outstanding properties as a subsistence food crop in the drought prone regions of South Asia and East Africa. It is primarily grown by marginal, small and poor farmers practicing rainfed and subsistence agriculture on degraded soils in dry, drought prone and hilly regions of India, Nepal, Bhutan and Sri-Lanka. India is the largest producer of finger millet (area 1.78 M ha and production 2.74 M t). Finger millet, among small millets, has received a little more attention than the rest in Uttarakhand and many southern states (Seetharam, 1998). Finger millet along with other millets is staple food among cereals with 60-65% area under hilly conditions of Uttarakhand.

Rice bean **(***Vigna umbellata* Thunb.) Ohwi and Ohashi is a native of South and South East Asia and is mainly confined to tribal regions of north-eastern hills, western and eastern ghats and peninsular India and hilly tracts (Chandel *et al.,* 1988). In Uttarakhand state, finger millet or *mandua* is a major staple cereal diet of the hilly people and the mainstay of sustainable production under hill farming system (0.14 M ha). It contributes 0.20 M t, which is 22.2% of the total cereal production in the state. It is primarily grown as rainfed crop at higher elevations in the month of April. Gobhi sarson (*Brassica napus* L.) is an oilseed crop of

Mediterranean region and a recent crop introduction to India, and has shown excellent performance in region with cooler climates, especially in the hill zones of Himachal Pradesh and Punjab, and is gaining acceptance in Uttarakhand and Haryana (Yadav *et al.,* 1999). The yield potential of field crops grown in different segments of the waterway from 2004 to 2008 is given in Table 1.

The average national productivity of finger millet is 15.0 q ha^{-1} but the productivity of finger millet in water way ranged from 4.2 q ha^{-1} to 8.1 q ha^{-1}. The average rainfall during the *kharif* crop season (June to October) is presented in Table 2 alogwith 48 years average rainfall.

There was a gradual increase in the grain productivity potential of finger millet from 4.2 q ha^{-1} to 8.1 q ha^{-1} except in the year 2007-2008 where it declined slightly (6.8 q ha^{-1}). This could be attributed to acute moisture deficit of 144 mm and 63 mm in July and June 2007, respectively, whereas in 2008 rainfall was in excess (Table 2).

The increasing trend in the finger millet productivity could also be attributed to gradual fertility build up in the waterway segment as the stover was ploughed back in the field during the end of *kharif* season, and the growing of lentil, a leguminous crop whose below ground and above ground parts helped in improving the soil fertility.

The average grain yield of rice bean grown in waterway was 4.89 q ha^{-1} maturing in 147 days while the average yield of rice bean cultivars has been reported from 7.57 q ha^{-1} to 8.85 q ha^{-1} (Dutta *et al.,* 2000). The rice bean green biomass productivity ranged from 33.8 q ha^{-1} to 44.8 q ha^{-1} in the years 2007 and 2008, respectively maturing in 144-167 days.

It was observed in Table 2, that only in the year 2008, the rainfall was in excess (1586 mm) of the long-term average rainfall (1374 mm). While in the remaining years the deficit ranged from 193 mm to 477 mm during the crop season. Since rice bean is a long duration crop, moisture deficit of 144 mm and 100 mm during July, 2007 and August, 2006 during the vegetative stages of the rice bean crop declined the biomass productivity of rice bean.

The rice bean crop has low harvest index at 0.25 and high biomass production levels. The average green biomass productivity levels during 2004-2008 at 3.6 t ha^{-1} are encouraging for fodder purposes and because it is harvested after the withdrawal of monsoon in the month of October. Highest seed yield of 16.41 q ha^{-1} was reported by Singh, 2010 under best management conditions in Himachal Pradesh. The yield of gobhi sarson was very low in 2007-2008 while it was 4.90 q ha^{-1} maturing in 155 days in 2008-09. This could be attributed due to better distribution of winter rainfall (Table 3).

Water use for evapo-transpiration (ET) demand of *P. maximum* was the lowest (145.5 mm) followed by lentil (153.0 mm) and *B. napus* (160.5 mm). The yield of *rabi* crops realized in waterways under rainfed situations was low because of the prevailing degraded conditions as well as shadow effect of the adjoining sal forest.

Table: 1
Productivity levels (q ha^{-1}) and maturity duration of crops (*kharif* and *rabi* seasons) during the period 2004-2008 are given as under

Segments	Crops	Yield 2004-05	Yield 2005-06	Yield 2006-07	Yield 2007-08	Yield 2008-09
II	Finger millet (*Eleusine coracana*)	4.2± 1.1 (88-100)	4.6± 0.8 (120)	7.6± 1.2 (98)	6.8±1.5 (126)	8.1±2.2 (94)
I	Rice Bean (*Vigna umbellata*)	41.1± 7.8 (144)	49.0 ±4.9 (147)	35.5 ±4.9 (149)	33.8±3.18 (167)	44.8 ± 6.8 (161)
II	Lentil (*Lens culinaris*)	3.7±0.30 (156)	3.5±0.28 (142)	2.0±0.06 (160)	1.8±0.2 (137)	1.58±0.10 (140)
I	Gobhi Sarson (*Brassica napus*)	3.0±0.09 (128)	2.9±0.85 (152)	3.50±0.64 (166)	1.7±0.03 (149)	4.90±1.6 (155)

Figures in parentheses indicate the days to maturity

Table: 2
Rainfall during *kharif* season (mm) from 2004 to 2008

Months	Rainfall (mm)					
	48 years Average	2004	2005	2006	2007	2008
June	170	163(-7)	109(-61)	89(-81)	107(-63)	301 (+131)
July	488	191(-297)	511(+23)	667(+179)	344(-144)	559(+71)
August	468	440(-28)	239(-229)	368(-100)	493(+25)	634(+166)
September	204	41(-163)	303(-99)	36 (+168)	73(-43)	72(-132)
October	44	62(+18)	6(-38)	21(-23)	1(-43)	20(-24)
Total	1374	897 (-477)	1168 (-206)	1181(-193)	1018 (-356)	1586 (+212)

Figures in parentheses indicate the differences of rainfall over the 48 years average in deficit (-) or excess (+).

Table: 3
Rainfall distributions in *rabi* season (mm) during 2004-08

Months	Rainfall (mm)					
	48 years Average	2004-05	2005-06	2006-07	2007-08	2008-09
November	3.8	0.0 (-3.8)	0.0 (-3.8)	0.6 (-3.2)	0.0 (-3.8)	10.6 (6.8)
December	13.8	4.7 (-9.1)	4.7 (-9.1)	23.0 (9.2)	10.9 (-2.9)	0.0 (-13.8)
January	48.4	91.6 (43.2)	59.9 (11.5)	0.0 (-48.4)	14.3 (-34.1)	1.2 (-47.2)
February	56.7	8.5 (-48.2)	74.6 (17.9)	121.2 (64.5)	15.4 (-41.3)	28.5 (-28.2)
March	42.5	0.0 (-42.5)	52.8 (10.3)	94.9 (52.4)	1.8 (-40.7)	8.6 (-33.9)
April	28.2	15.4 (-12.8)	0.0 (-28.2)	3.8 (-24.4)	35.8 (7.6)	13.8 (-14.4)
May	46.6	57.8 (11.2)	6.8 (-39.8)	82.8 (36.2)	58.4 (11.8)	60.5 (13.9)
Total	34.3	25.4 (-8.9)	28.4 (-5.9)	46.6 (12.3)	19.5 (-14.8)	17.6 (-16.7)

Conservation of Natural Resources

Use of legume either as pure or intercrop, is the cheapest soil conservation measure to combat soil erosion and soil fertility losses as they provide appropriate protective cover to the soil which help in intercepting raindrops so as to expose minimum soil surface for erosion. Inclusion of such type of close growing vegetation in the cropping system either as pure crop or intercrop reduces soil erosion (upto 27%), water losses (upto 15%) and adding organic matter in soil resulting in increase of succeeding crop (61% in case of wheat). Legumes also lower the value of C factor and decrease the quantity of soil lost from the cultivated lands (Sharda *et al.,* 2009). The deposition of fresh soil particles brought along with runoff water in the waterways in segment II and III was to the tune of 15.41 cum and 25.4 cum, respectively as per the profile study, which could have been deposited in the farm pond hereby adversely affecting the life of farm pond. The technology of utilizing the waterways by growing cereals, pulses, oilseeds and grasses will be useful for restoration of such degraded lands.

Rice bean provided a very good canopy cover over the soil, covering 80% of the area within 40 DAS (Fig. 3). Similarly finger millet, a traditional staple cereal crop, provided 40% cover by 15th July and 60% crop cover by 30th July. Finger millet was sown at 30 cm row spacing and narrow spacing (7.5 cm) for plant to plant providing greater resistance to runoff. Besides, it behaved like grasses in respect of its root binding capacity and was quite effective in controlling soil loss. In the present study, the rice biomass was ploughed back in the soil to improve the soil fertility.

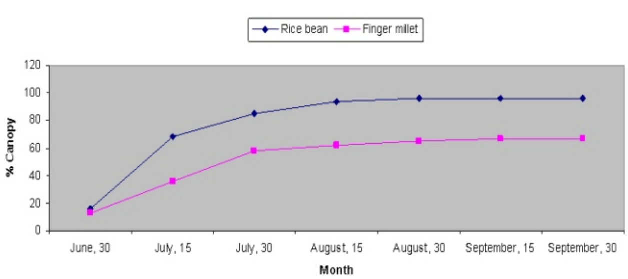

Fig. 3. Canopy cover of rice bean and finger millet in 2008

Integration of rice bean is, therefore, advocated not only in improving the biomass productivity for nutritional security but also for conserving the natural resources and improving the soil fertility. The profile survey indicated that there was net deposition of the sediment to the tune of 15.41 cum and 25.4 cum in segment II and III, respectively. Subsequent designing and reshaping the waterway has resulted in only 4 overflows from the farm pond.

Performance of Guinea Grass

Guinea grass (*P. maximum* Jacq.) is an important fodder grass throughout the tropics (Burton *et al.,* 1973). It has good yield potential (70-100 t ha^{-1}) in India as reported by Kaushal *et al*., 1999 and produces high quality forage under optimum management (Hazara, 1995). It is fairly tolerant to drought and shade with dry matter production of 4-12 t ha^{-1}. In the sub-montane areas of Himachal Pradesh, production of 7.16 t ha^{-1} of dry matter in eight cuttings has been reported (Singh *et al.,* 1998). Similarly, Bhardwaj and Sindhwal (2007) reported the dry matter production of 1.54 t ha^{-1} in Dehradun at 4% slope. In the present study, Guinea grass was harvested during 2008-12 with the average production of 18.73 t ha^{-1}. The average height of grass was 1.73 m, clump diameter of 40.3 cm, number of tillers 22.4 and green biomass production 18.73 t ha^{-1}.

Performance of Lemon and Lemon Grass

Lemon grass was planted in 2015 in segments I and II. The average yield of 1.08 t ha^{-1} and 0.94 t ha^{-1} was obtained in the years 2016 and 2017, respectively in segments I while it was 0.81 t ha^{-1} and 0.74 t ha^{-1} in 2016 and 2017, respectively in segment II. However, average herbage yield of lemon grass that was as high as 16.3 t ha^{-1} to 19.8 t ha^{-1} has been realized at farm (Tomar *et al*., 2019). The lower herbage yields of lemon grass in the waterway could be attributed to shade effects of the lemon plants planted on the side slopes as well as natural shading due to sal forest and mango trees, besides continuous flow of water in the waterway from the catchment area 15 ha).

Eureka lemon plants planted on the side slopes established well after three years of planting. The survival

Finger millet

Rice bean

Gobhi sarson

Lemon on side slope

Fig. 4. Field view of crops and fruit plants in waterway

Table: 4
Growth and yield performance of guinea grass from grass water way 2004-12

Sample	Plant height (cm)	Clump (cm) Diameter	Tillers clump (No)	Green biomass (t ha^{-1})
1	1.8	47.7	15.6	22.5
2	1.6	41.2	23.4	15.0
3	1.8	32.1	28.2	18.7
Av.	1.73	40.3	22.4	18.73

of lemon plants was 93.1%. The average height of the plants varied from 0.95 m to 1.96 m with an average diameter of 1.7 cm. The crown size varied from 0.3 m to 1.3 m in 2005-2006. Plants have come to flowering, producing 2.5 kg plant^{-1} to 3.0 kg plant^{-1}. Average fruit yield of lemon was recorded as 11.18 (9.45-13.12), 10.05 (8.08-11.12) and 8.75 (7.35-10.00) t ha^{-1} during 2008-2016 in I, II and III segments, respectively (Fig. 5). First segment produced highest average fruit yield, which was 11.26% and 27.78% higher than second and third segments of waterway. The segment I was close to sal forest, which was enriched with more organic matter as leaf litter contributed by sal forest followed by second segment while third segment was far away, which could not be enriched by organic carbon by sal forest as shown in Fig.1.

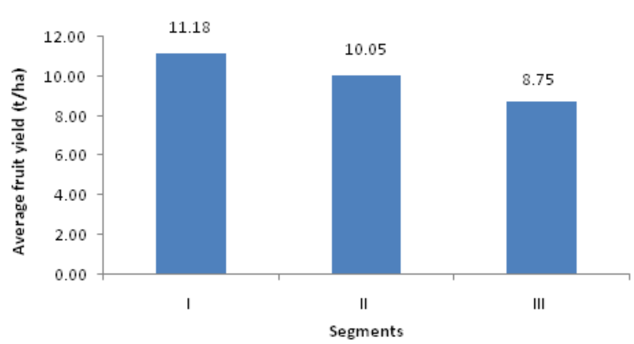

Fig. 5. Fruit yield of lemon during 2008-16

4. CONCLUSIONS

Grassed waterways are useful for agricultural lands to drain off excess runoff safely and preventing the soil loss.

The entire stretch of 1.3 km long natural waterway at the Research Farm Selakui, Dehradun, was reshaped in trapezoidal shape in three segments with bed slopes of 1.0%, 1.3%, and 1.6% from top to bottom. The productivity potential of native erosion resisting crops like finger millet, rice bean, gobhi sarson and lentil was assessed, which was as high as 8.1%, 3.7%, and 4.9% under cereal, pulse and oilseed crops. The highest biomass productivity of rice bean was recorded at 49.0 q ha^{-1}. In the present study, Guinea grass was harvested in the month of October with the average fresh biomass production of 18.76 t ha^{-1}. Lemon productivity realized on side slope of waterway was maximum (11.18 t ha^{-1}) in the first segment and declined gradually towards waterlogged area. Such productivity levels of crops at degraded sites of the waterway are substantial in view of experimental area on one side being surrounded from one side by tall sal forest trees. The reshaped waterway not only was put to productive use where nothing grew before, but also helped in conservation of soil and natural resources.

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