EFFECT OF CLEARING NATIVE FOREST (CAATINGA) STRIPS ON SOME HYDROLOGIC COMPONENTS OF MICRO-WATERSHEDS[1]

PREM N. SHARMA[2] and ADERALDO DE S. SILVA[3]

ABSTRACT - The influences of clearing native vegetation (Caatinga) in contour strips at 25 cm vertical interval on evaporation losses in cleared strips, annual runoff efficiency and annual soil loss on gently sloped micro-waterheds in the arid zones of Northeast Brazil are reported. The alternate native vegetation (Caatinga) strips function very effectively as windbreaks thus reducing evaporation losses substantially in the leeward cleared strips. The runoff measured at the micro-watershed with cleared strips was many-fold lower than the runoff obtained at a completely denuded watershed even when it was protected by narrow based channel terraces. However, the annual runoff efficiency can be significantly increased in a strip cleared watershed if narrow based channel terraces are provided on the lower side of cleared strips. The annual soil losses in strip cleared watersheds as well as completely denuded watershed of gentle slopes were negligible. Thus clearing land in alternate contour strips on a micro-watersheds shall substantially improve crop water use efficiency without creating any significant erosion problems. Additionally this treatment will increase runoff for water harvesting for irrigation purposes.

Index terms: forest watershed management, windbreaks, irrigation of arid lands.

EFEITO DO DESMATAMENTO EM FAIXAS DE VEGETAÇÃO NATIVA DE CAATINGA SOBRE ALGUNS COMPONENTES HIDROLÓGICOS DE MICROBACIAS HIDROGRÁFICAS

RESUMO - São analisadas, neste trabalho, para áreas de microbacias hidrográficas, com declividade natural leve do terreno existente na região árida do Nordeste brasileiro, a influência do desmatamento da vegetação de caatinga em faixas de contorno, sobre a redução das perdas de evaporação e de solo, e a eficiência da água de chuva proveniente do escoamento superficial. Identificou-se que as faixas desmatadas, alternadas com faixas de vegetação nativa, as quais funcionam como quebravento, têm efeito significativo sobre as perdas por evaporação nas faixas limpas, e que a produção de escoamento superficial nas microbacias com faixas desmatadas é menor do que nas microbacias desnudas, embora essas tenham terraços do tipo canal com base estreita. Por outro lado, as perdas de solo anuais, tanto nas microbacias com faixas desmatadas como naquelas totalmente desnudas, com declividade natural leve do terreno, são abaixo dos limites erosivos permitidos. Conclui-se, então, que o desmatamento das terras, tendo como base as microbacias hidrográficas desmatadas em faixas de contorno alternadamente com faixas de vegetação nativa, permitirá um aumento substancial na eficiência de uso de água pelas culturas em bases conservacionistas, e ainda poderá incrementar a indução do escoamento superficial, se se construírem terraços do tipo canal com base estreita no lado mais baixo das faixas limpas, para fins de armazenamento e irrigação.

Termos para indexação: manejo de bacias florestais, quebraventos, irrigação de terras áridas.

INTRODUCTION

Natural and artificial windbreaks have been used all over the world in dry climates for reducing evaporation (Yu 1982), conserving soil moisture (Lynch et al. 1980), controlling wind velocities (Bhimaya 1976), reducing crop water requirements (Rehman 1978) and soil conservation (Gupta et al. 1983). While these influences of windbreaks are well known for a long time, their widespread use in arid and semi-arid zones is now being propagated on a large scale in developing countries. In Brazil recommendations on use of windbreaks for dry zones were made as early as 1972 (Tigre 1972).

In Northeast Brazil, new areas are being cleared of native forest (Caatinga), often indiscriminately, for rainfed or irrigated agriculture. This results in complete removal of natural vegetative cover on

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[2] Ph.D. (Engineering), Irrigation Specialist, Inter-American Institute for Cooperation on Agriculture (IICA) at EMBRAPA/CPATSA, Caixa Postal 23, CEP 56300 Petrolina, PE, Brazil. Present Address: Coordinator/ Watershed Management Expert, FAO/UNDP, Vientiane, LAOS, C/o ESCAP Pouch Unit, U.N. Building, Rajdamnern Avenue, Bangkok, Thailand.

[3] M.Sc., (Irrigation), Researcher, EMBRAPA/CPATSA, Caixa Postal 23, CEP 56300 Petrolina, PE., Brazil.

the soil. Caatinga is extremely well adapted to the arid region and is one which must have evolved over ages into an extremely drought resistant native vegetative cover. It is extremely efficient at soil and water conservation (Sharma & Silva 1986), provides fodder for animals and serves many other useful purposes. The hypothesis of this paper is that new land for agriculture could be cleared in contour strips in such a way that alternate strips of Caatinga (native vegetation) can function as windbreaks.

The authors (Sharma et al. 1984, Sharma & Silva 1986) have recently published the details of a research project on runoff inducement for agriculture in Northeast Brazil where the important treatments consist of clearing alternate contour strips of Caatinga on a micro-watershed bases for water harvesting, while at the same time conserving soil and ecosystem.

The objective of this paper is to report the results of a study on the effects of use of alternate parallel contour strips of Caatinga as windbreaks on (1) evaporation losses (in turn crop water use) in adjacent alternate cleared strips of land, and (2) other hydrologic components like annual runoff and soil erosion, on a natural micro-watershed bases.

MATERIALS AND METHODS

The experiment consisted of four micro-watersheds on Oxisols developed at the research station of the EMBRAPA/CPATSA, Petrolina (PE), Brazil. The micro-watersheds varying in size from approximately 1 to 2.1 ha. land consisted of four treatments of land and native vegetation management. Figure 1 shows the layout of three micro-watersheds numbered here as A, B and C. The fourth micro-watershed (D) is not shown here as it was a treatment without Caatinga. Table 1 describes the most important characteristics of the micro-watersheds and the management treatments. The predominant wind direction was south-east.

The experimental work consisted of topographic survey of the area before any land clearing to delineate the independent micro-watershed units. Therefore, a contour map of 25 cm vertical interval contour lines was prepared. On watersheds A and B, 25 cm contour lines were marked down and alternate strips between two 25 cm contour lines cleared of the native vegetation by bulldozer. Thus, each set of a 25 cm vertical interval contour strip of native vegetation and a 25 cm vertical interval cleared contour strip was located at a vertical interval of 50 cm.

Surface drains of 1 m width and 15 cm depth were made at natural drainage paths in the watersheds and grassed. In watershed B, narrow based channel terraces of a maximum of 1 m^2 cross section were constructed at 0.3% slope below each cleared strip. Watershed C was not at all disturbed and left completely under native vegetation. The fourth watershed (D) was completely cleared of Caatinga and two narrow based channel terraces were laid out at 1 m vertical interval. Surface waterway of 1 m width and 15 cm depth was provided in watershed D as a natural drainage path. All the four watersheds were independently monitored for runoff by installing Parshall flumes and stage recorders at the outlet of the drainage of each watershed. A collector drain was developed to remove the water of watershed B so that it would not interfere with the hydrologic water balance of the watershed C.

To establish the effects of Caatinga strip on the evaporation losses in the leeward cleared strips, three USDA Class A pans were installed at 5, 15 and 25 m horizontal distance from Caatinga strip in one of the cleared strips of watershed B. Daily observations of evaportation were taken after the rainy season from April 26 to Sept. 25, 1984 (total 5 months period). The average width of the cleared strips was about 30 m for the given slopes of the watersheds (Table 1). The average height of Caating was 4.5 m. Additionally, to determine the distance up to which Caatinga has a positive effect on evaporation reduction, four evaporation pans were installed at 30 m, 40 m, 50 m, and 60 m distance on the leeward side of a Caatinga area, in a completely open field for a month. Daily records of wind velocity were maintained and average weekly values calculated. The daily records of evaporation were added to give weekly values.

For arid zones of Northeast Brazil, in areas with complete native vegetation cover on gentle slopes, no significant amount of runoff is produced (Sharma & Silva 1986). Hence a treatment which reduces evaporation losses (and thus reducing infiltration losses also due to increased moisture content of soil), on the one side, but increases annual runoff efficiency without causing additional erosion on the other side should give extra water for harvesting into small reservoirs for life saving irrigations.

To establish this, annual runoff efficiency was obtained by summing up the daily runoff data calculated from stage recorder charts of the installed Parshall flumes and then dividing the annual runoff by annual rainfall. To estimate annual soil loss, water samples were collected manually from the Parshall flume during each runoof occurrence. However, during 1983-84 this was not possible, hence water samples were drawn from the leftover water in the flumes after a runoff event. While this is not an accurate way to measure soil loss, this data of 1983-84 can still be used for comparison of various treatments within the same year.

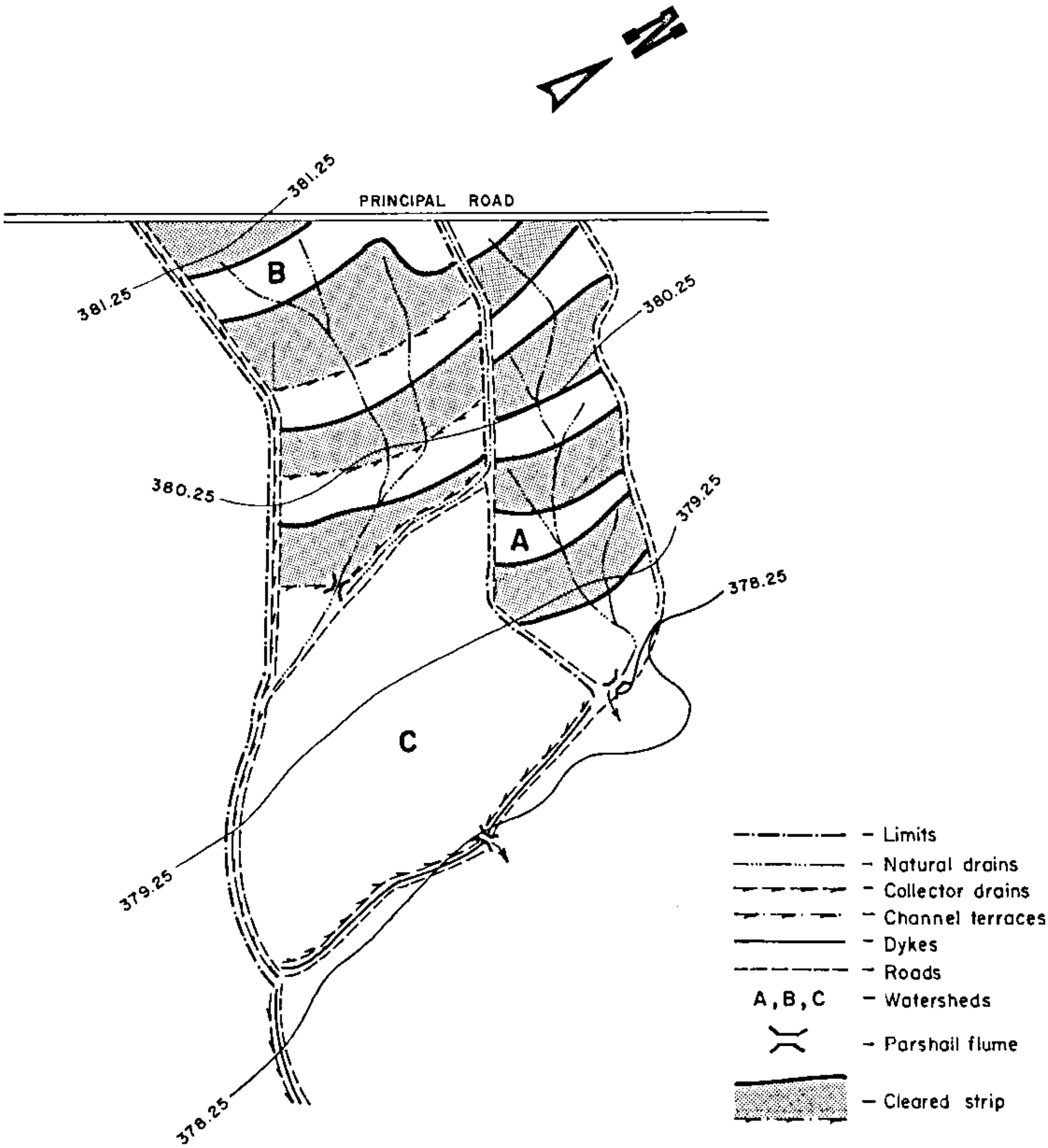

FIG. 1. Layout of various micro-watersheds with (A, B) and without (C) cleared strips, scale 1:4285.

TABLE 1. Details of various treatments and characteristics of the micro-watersheds.

Watershed	Total area, ha	Slope, (%)	Area of vegetation strips, (%) of total	Drainage density, m/ha	Treatment
A	1.063	1.16	49.3	310.44	Strip clearing of Caatinga* + intensified surface drainage
B	1.402	0.75	50.0**	233.95	Strip clearing of Caatinga + intensified surface drainage + channel terrace below each cleared strip
C	1.609	1.18	100.0	0.0	Thick natural native vegetation (Caatinga) without any kind of disturbance, control
D	2.088	0.89	0.0	91.0	Completely denuded, no regeneration allowed, narrow based channel terraces at 1 m vertical interval.

* Caatinga is a natural and native vegetation of Northeast, Brazil.
** In 1983-84 this area was only 44% which was increased to 50% after this year.

RESULTS AND DISCUSSION

Effect of native vegetation (Caatinga) strips on evaporation losses in cleared strips

The weekly evaporation rates at 5, 15 and 25 m leeward distance from Caatinga nativa vegetation (Average height 4.5 m and dense), and in completely open areas, are plotted in Fig. 2 as function of time in weeks for the observation period of the five months. The weekly evaporation rates throughout the period and at each of the 3 distances from Caatinga strip, were lower than the open area evaporation rates. The evaporation rates in general increased as the dry season proceeded,

Table 2 shows the percentage of reduction in weekly evaporation that was achieved by the Caatinga strip as a windbreak at all the 3 distances from Caating strip, in comparison with the weekly evaporation rates in open area. The daily average wind velocities (km/day) during different weeks at a height of 50 cm in open area are also given.

The maximum reduction in weekly evaporation rate was at 5 m distance from Caatinga strip varying from 10.98 to 37.39%. The reduction at 15 and 25 m leeward distance from Caatinga strip varied from 8.66 to 36.82% and 6.45 to 21.57% respectively. Thus the evaporation losses were reduced by 6.45 to 37.39% within a leeward side distance of 25 m from the Caatinga strip. The reduction, though considerable at all the places in the 25 m distance, is of lesser magnitude as the distance from Caatinga strip increases. Also, the redution in weekly evaporation rates is generally higher at lower wind velocities and vice versa. Additionally, as the dry period proceeds, the percentage reduction in weekly evaporation losses goes down. This is because the leaves of Caatinga start falling as the dry season proceeds, thus creating more perforations in the windbreak and hence obstructing less and less wind. However, it is established by the data in Table 2 and Fig. 2 that at least up to 25 m leeward distance there is considerable reduction in the weekly evaporation rates by Caatinga strips throughout the dry season.

Table 3 shows percentage of decrease (negative sign) or increase (positive sign) in weekly evaporation rates beyond 25 m of leeward side of Caatinga strip at 30, 40, 50 and 60 m respecti-

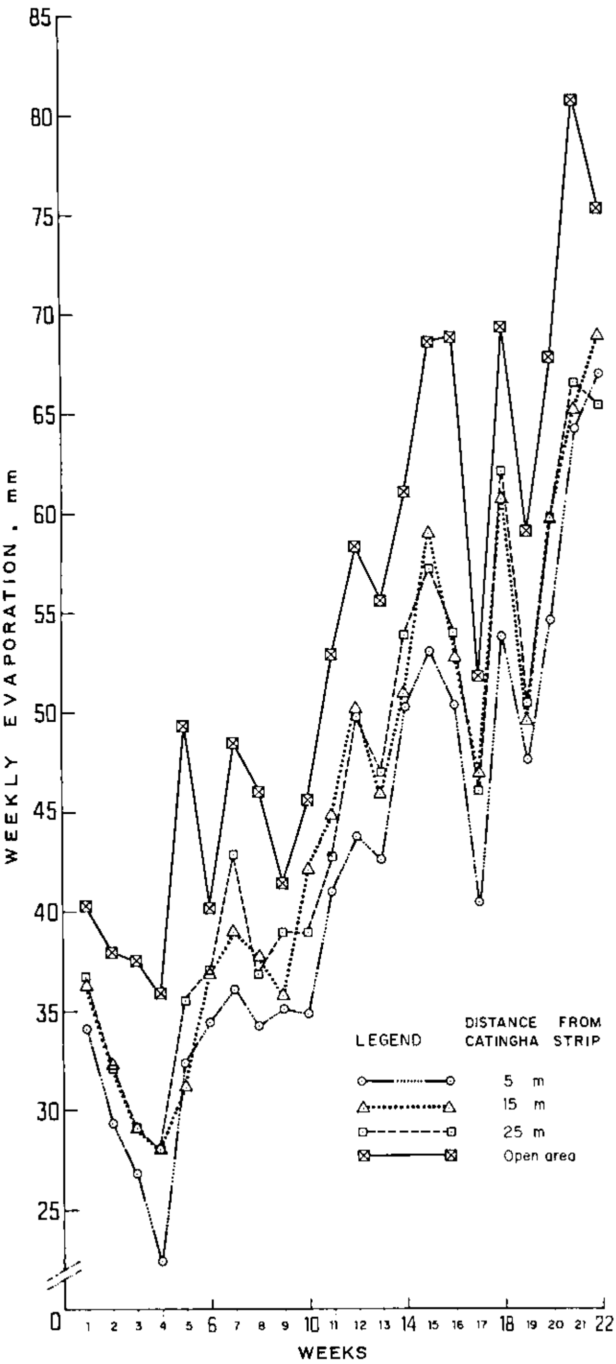

FIG. 2. Weekly evaporation at 5, 15 and 25 m distance from catingha forest in the cleared strip, and in open area.

TABLE 2. Effect of native vegetation (Caatinga) strips on the weekly evaporation losses of a cleared strip*.

Week** No.	Reduction in weekly evaporation rate, compared to evaporation rates in open area, at a leeward distance of .... from Caatinga strip, %			Average daily wind velocity in open area at 50 cm height,
	5 m	15 m	25 m	km/day
1	15.31	9.89	8.92	80.1
2	22.43	14.15	14.34	86.8
3	28.84	21.17	21.00	78.9
4	37.39	21.04	21.57	99.5
5	34.25	36.82	27.92	93.4
6	14.01	8.40	6.18	105.1
7	25.54	19.46	11.67	106.8
8	25.48	18.20	19.70	128.1
9	15.33	13.81	6.45	120.1
10	23.25	7.34	15.03	112.4
11	22.50	15.01	19.36	147.6
12	24.94	13.93	14.55	158.7
13	23.31	17.31	15.43	163.5
14	17.58	16.66	12.86	141.5
15	22.00	13.68	16.23	179.8
16	26.78	22.84	21.61	140.8
17	21.78	9.34	10,93	184.2
18	22.77	12.45	10.32	205.6
19	19.46	16.11	14.55	165.4
20	19.59	12.52	12.02	144.5
21	20.42	19.18	17.45	199.8
22	10.98	8.66	13.17	142.0

* Predominant wind direction south east.
** Beginning April 26, 1984.

TABLE 3. Effect of Caatinga strip on weekly evaporation losses in leeward cleared area beyond 25 m distance.

Week* No.	Percentage of decrease (–) or increase (+) in weekly evaporation rates beyond 25 m of leeward side of Caatinga strip as compared to open area, at a distance of				Average daily wind velocity in open area at 50 cm height,
	30 m	40 m	50 m	60 m	km/day
1	- 1.21	+ 1.18	+ 4.07	+ 9.46	113.4
2	- 4.26	- 3.67	- 3.67	- 3.36	118.0
3	- 0.05	+ 1.81	+ 4.45	+ 3.46	98.8
4	- 0.22	- 8.32	- 5.85	- 3.12	127.2

* Beginning Nov. 27, 1984.

vely. At 30 m there was always a reduction in weekly evaporation rates though of very low order varying from 0.05 to 4.26% only. At 40 m and beyond, there was no consistency in the percentage change oι weekly evaporation rates. Hence it follows, that up to 30 m distance there shall be beneficial effect of strips of Caatinga. Since evaporation rates are directly proportional to crop water use, there shall be substantial reductions in crop water use if crops are grown in the cleared strips up to 30 m from the caatinga strips. This will thus improve the water use efficiency of crops substantially.

Effect of cleared and caatinga strips on annual runoff and soil loss

The effects of various treatments of strip clearing with (watershed B) and without (watershed A) narrow based channel terraces in comparison with virgin Caatinga (watershed C) and completely denuded watershed (D) are summarized in Table 4. For more detailed data refer to Sharma (1985), and Sharma & Silva (1986).

While there was hardly any runoff in completely virgin Caatinga watershed C, the completely denuded watershed had substantially higher annual runoff efficiencies; 28.07 and 24.52% during 1983-84 and 1984-85, respectively. The figures of annual runoff efficiency for 1983-84 shown in brackets in Table 4 are the figures when first three rains totaling 98.1 mm which occurred between Nov. 28 to Dec. 4, 1983, are not considered. These data have been given to facilitate comparison of watershed A with other watersheds during 1983-84 period. The watershed A could not be monitored for the first 3 events due to delay in availability of a stage recorder.

The annual runoff efficiency of watersheds A & B is between the runoff efficiency of watersheds C & D, which shows the effects of cleared strips with (B) and without (A) narrow based channel terraces. The efficiency of watershed A is lower than that of watershed B. This is the effect of the narrow based channel terraces. A narrow based channel terrace does not permit the runoff of cleared strip to enter the Caatinga strip. Since the infiltration rates of Caatinga strip are higher as compared to the cleared strips, when runoff water enters the Caatinga strips a considerable part of it infiltrates into the ground (Sharma, 1985). Thus the narrow based channel terraces increase runoff which is a beneficial influence if increased inducement of runoff is to be obtained for water harvesting for irrigation (Sharma & Silva 1986). The reasons for the difference in the behaviour of the watersheds from one year to another have been

TABLE 4. Effect of various treatments of strip clearing with (B) and without (A) narrow based channel terraces in comparison with virgin Caatinga (C) and completely denuded watershed with narrow based channel terraces (D) treatments on Oxisol micro-watersheds.

Micro-watershed unit	Annual[1] Runoff efficiency[2] (%)		Annual soil loss (kg/ha)	
	1983-84	1984-85	1983-84[3]	1984-85
A	(3.72)[4]	1.05	45.21	9.03
B	10.77 (10.00)[5]	5.46	135.32	42.93
C	0.028 (0.03)	0.0	1.0	0.0
D	28.07 (29.67)	24.52	141.33	233.2

1 For 1983-84, from Nov. 28, 1983 to May 30, 1984, total rainfall was 601 mm. For 1984-85, from Nov. 15, 1984 to May 30, 1984, total rainfall was 775 mm.

2 Annual runoff efficiency is defined as the percentage of runoff produced by the rainfall on an annual basis.

3 Estimate based on water samples from left over runoff in Parshall flumes at the end of a runoff event.

4 The first 3 runoff events could not be recorded.

5 The data in brackets is when the first 3 runoff events are removed. Thus the figures in brackets can be directly compared.

explained elsewhere (Sharma & Silva 1986). The major reason being that while only 601 mm of rainfall was received in 1983-84 as compared to 775 mm in 1984-85, many more higher intensity rainfall events occurred in the first year while the second year had many more non runoff producing rainfall events.

The annual soil loss (Table 4) has in general been of very low order and of insignificant magnitude for all the four treatments. This is so because the slopes of the watersheds (Table 1) are gentle. However, while comparing the treatments, the watershed D (completely denuded) obviously had the maximum erosion though the amount was insignificant.

The best treatment which reduces evaporation losses but increases runoff for water harvesting without creating erosion problems is the treatment with cleared Caatinga strips and channel terraces on micro-watershed unit B.

CONCLUSIONS

1. If the land is cleared in strips, the Caatinga strips very effectively function as windbreaks and very substantially reduce evaporation losses in the cleared strips.

2. In the given conditions of climate and topography and the native vegetation, the maximum width of cleared strip of Caatinga should be about 30 m.

3. The runoff in strip cleared watersheds is substantially lower than completely denuded watersheds. The annual soil loss in general at the gentle slopes is insignificant.

4. If runoff is to be induced for water harvesting for irrigation purposes, the treatment of narrow based channel terraces located below the cleared strips can have an approximate annual runoff efficiency of 5 to 11% compared to zero for watershed with complete native vegetation cover. This, in addition, shall reduce the evaporation losses by about 6 to 37% over a width of 25 m of the cleared strips.

REFERENCES

BHIMAYA, C.P. Shelterbelts; functions and uses. In: CONSERVATION in arid and semi-arid zones. Rome, FAO, 1976. p.17-28.

GUPTA, J.P.; RAO, G.G.S.N.; GUPTA, G.N. Soil drying and wind erosion as affected by different types of shelterbelts planted in the desert region of Western Rejasthan, India. **J. Arid Environ.**, 6(1):53-8, 1983.

LYNCH, J.J.; ELWIN, R.L.; MOTTERSHEAD, B.E. The influence of artificial windbreaks on loss of soil water from a continuously grazed pasture during a dry period (Water stress, pasture production). **Aust. J. Exp. Agric. Anim. Husb.**, 20(103):107-4, 1980.

REHMAN, S. Effect of shelterbelts on yield of wheat crop in Mastung valley Baluchistan. **Pak. J. For.**, 28(1):4-6, 1978.

SHARMA, P.N. **Final report of consultancy.** Brasília, Inter-American Institute for Cooperation on Agriculture, 1985. p.73-89.

SHARMA, P.N. & SILVA, A.D.S. **Native forest (caatinga) watershed management for runoff inducement for irrigation.** s.l., 1987. p.73-84 (Forest Ecology and Management, 18)

SHARMA, P.N.; ALONSO NETO, F.B.; PORTO, E.R.; SILVA, A. de S. Runoff inducement for agriculture in very arid zones of the Northeast Brazil. **Pesq. agropec. bras.**, 19(8):1011-19, 1984.

SHARMA, P.N. & SILVA, A.D. de. Native forest (Caatinga) watershed management for runoff inducement for irrigation. **Forest Ecol. Manag.** Amsterdam, (18): 73-84, 1987.

TIGRE, C.B. **Quebraventos e faixas de proteção para a zona seca.** Fortaleza, DNOCS, 1972.

YU, F.C. Wind tunnel experiment on the effects of wind reduction on the leeward of windbreaks with different thicknesses. **J. Agric. For.**, 31(1):99-127, 1982.