Chapter 5

Competition for Soil Moisture Between Hedgerows and Crops in a Contour Hedgerow Intercropping System

Philippe Jobin and Tang Ya

INTRODUCTION

Water is a major limiting factor for crop production, especially in arid and semiarid regions and regions with a long dry season. Nepal has a typical monsoon climate characterised by a dry season of about 7-8 months, during which only some 20% of annual precipitation falls. A large part of the agricultural land in Nepal is rainfed: more than 1 million hectares of cultivated land in the hill and mountain areas has no irrigation (Tulachan 2001). The major problem with farming sloping cropland is soil erosion. Terracing is the response of mountain people to this problem; it is widely used for cultivation in slope areas (Ojha 1997). Around 30% of the erodible agricultural land in the hills of Nepal (365,000 ha) has been terraced (Yadav 1998). This practice is effective in retaining rainfall water on terraces (Stallings 1957), which controls runoff and hinders soil erosion (Finkel 1986).

Sloping agricultural land technology (SALT), also known as contour hedgerow intercropping technology (CHIAT), is an effective alternative to the classical man-made terrace. It has almost all the functions of a hand cut terrace, but the terraces are developed by planting fast growing perennial woody tree or shrub species along contour lines. The hedgerows create a living barrier that traps sediments and gradually transforms the sloping land to terraced land forming a 'bioterrace'. Bioterracing involves important modifications to the land over time and the incorporation of trees and shrubs into the agricultural system is certain to lead to a number of changes; there could be a redistribution of soil water in the soil profile, for example. Another common criticism of SALT is the possibility of competition with crops for limited water resources. There have been several reports from tropical areas that indicate that moisture competition between hedgerows and associated crops can be a major problem when a hedgerow intercropping system is used in a dry area, particularly when the hedgerows are closely spaced (Singh et al. 1989), and that this can reduce crop yield.

ICIMOD, in collaboration with national institutions, has introduced the contour hedgerow technology to the subtropical to warm temperate areas of the HKH region. The climate and water resource regime prevailing in the HKH region are different from those in the tropics. Since the productivity of rainfed land during the dry season is strongly dependent on the moisture available to the crop, it is important to determine whether or not there is a competition between hedgerows and crops in this different climate.

In the following, we describe the results of an experiment to quantify the soil moisture relationship between hedgerows and companion crops at a site in the mid hills of Nepal. The main aim was to investigate the spatial moisture distribution in a terrace developed by planting hedgerows of *Alnus nepalensis,* and to determine whether there was any competition between the hedgerow and the crop for the water resources by means of modelling.

Material and Methods

Site description

The experiment was conducted at ICIMOD's Godavari Trial and Demonstration Site (see Chapter 1) on a rainfed outwardly-sloping terrace (around 5 degrees) established with hedgerows of *Alnus nepalensis* (utis). The hedgerows had been established with seedlings in 1993 and occupied about 17% of the land space of the terrace.

Experimental design

The experiment was carried out in parallel with the experiments on nutrient competition described in Chapter 4.

The experiment consisted of two treatments with three replicates. Treatment 1 was with cultivation of crops and Treatment 2 without crops. The two treatments were arranged alternately along one alley with a gap between treatments. For the treatment with crops, maize was sown in April and harvested in September, and radish was sown in October and harvested in March. The first crop, radish, was sown in September 1998 and the last crop, also radish, was sown in October 2000. The crops were planted in rows (C1 and C2 in Figure 5.1). A locally purchased concentrated organic fertiliser 'kisan mal' was applied to the treatment plots with crops at a rate of 16 t/ha (1.6 kg/m^{2}) for each planting season before sowing; its nutrient composition is 3% N, 5% P_2O_5, and 2% K_2O (see Chapter 2).

The maize crop was harvested and the fresh weight of crop biomass and the grain weight determined. Samples were taken for oven-drying to obtain the weight of dry matter. Only the fresh weight of radish was determined.

The soil water content was followed indirectly using soil tension measurements performed with a tensiometer gauge (H&TS Electronics Ltd, Healesville, Australia) and tensiometer tubes. The tensiometer tubes were placed at three positions of increasing distance from the hedgerow in between the rows of crops as shown in Figure 5.1: P1 (20 cm from hedgerow), P2 (140 cm from hedgerow), and P3 (260 cm from hedgerow). The tubes were placed at four depths at each position: D1 = 10 cm, D2 = 30 cm, D3 = 50 cm, D4 = 70 cm (Figure 5.1). The tensiometers were not disturbed by the soil sample collection that was performed in parallel (see Chapter 4 and Figure 4.1). The soil tension data collection started in June 1999 and was continued at five-day intervals until December 2000.

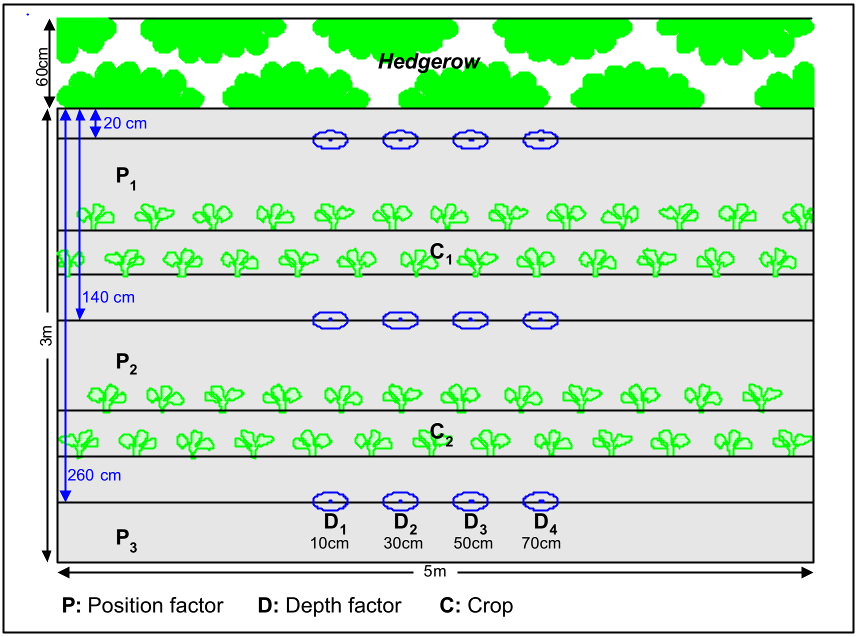

Figure 5.1: Experimental design (one block)

The design was a split block with three replicates. The treatment structure was factorial with the Position in the main plot, and the Depth and Time in a subplot. The statistical analysis was performed with Genstat Second Edition™ software. An analysis was performed for the complete data set, and for the dry season and rainy season data separately. The homoscedasticity and normality were verified using a residual versus fitted values plot and a histogram of residuals, respectively.

Modelling

The potential competition for water between hedgerow and maize was investigated by estimating the water consumption of each. The consumptive use of water was determined with an empirical method based on the Penman-Monteith approach (Verhoef and Feddes 1991). The potential evapotranspiration was determined from the following formula (Feddes and Lenselink 1994):

$$ET_p = K_c \, ET_h \qquad (1)$$

Where

ET_p = potential evapotranspiration
K_c = crop coefficient
ET_h = reference evapotranspiration

The hedgerow coefficient was estimated as 1.0 based on a tea crop with more than 70% ground cover (Doorenbos and Pruitt 1977). A maize coefficient of 0.86 was assumed (Arora 1996). The reference evapotranspiration was calculated from the following formula (Verhoef and Feddes 1991):

$$ET_h = \left(\frac{\Delta}{\Delta + \gamma *}\right) R'_n + \left(\frac{\gamma}{\Delta + \gamma *}\right) E_a \qquad (2)$$

Where

ET_h = reference crop evapotranspiration rate (mm/d)
Δ = slope of vapour pressure curve at T_a (kPa/°C)
γ = psychrometric constant (kPa/°C)
γ^* = modified psychrometric constant (kPa/°C)
R'_n = radiative evaporation equivalent (mm/d)
E_a = aerodynamic evaporation equivalent (mm/d)

The reference evapotranspiration term was calculated assuming a crop average height of 60 cm, a canopy reflection coefficient (albedo) of 0.23, and a canopy resistance equal to 70 s/m.

The computation method required the following meteorological data:

minimum and maximum temperature (°C)
solar radiation (W/m^2)
relative duration of bright sunshine (-)
average relative humidity (%)
wind speed (m/s)

These parameters were collected from a meteorological station located at about 250m from the experimental site, except for the solar radiation, which was estimated from the following equation (Feddes and Lenselink 1994):

$$R_s = \left(a + b\frac{n}{N}\right) R_A \qquad (3)$$

Where

R_s = Solar radiation (W/m^2)
a = fraction of extraterrestrial radiation on overcast days (-)
a + b = fraction of extraterrestrial radiation on clear days (-)
R_A = extraterrestrial radiation, or Angot value (W/m^2)
n = duration of bright sunshine (h)
N = day length (h)

The potential evapotranspiration term was calibrated by a factor of 0.50 to take into account the fact that the hedgerow has an effect on soil moisture further from its canopy. The hedgerow's canopy (500m x 0.60m) covered a surface of $300m^2$. The surface area explored by the roots is approximately $600m^2$ (1.20m x 500m). The 1.20m value was determined by excavating *Alnus nepalensis* plants. The calibration factor was obtained from the ratio between the surface covered by the hedgerow and the surface explored by the roots ($300m^2$ / $600m^2$ = 0.50).

The potential evapotranspiration of the hedgerow, expressed in millimetres, was transformed into volumetric water content using the following equation (Musy and Soutter, 1991):

$$\theta_v = \frac{ETp}{(a-b)} \qquad (4)$$

Where

q_v = volumetric water content (vol/vol per day)
ET_p = potential evapotranspiration (mm/d)
a–b = depth of soil explored by the roots (mm)

Excavation of *Alnus nepalensis* plants showed that the roots could extract water up to 800 mm from the surface (a = 800 and b = 0); a rooting depth of 700 mm was assumed for maize. The modification of the volumetric water content of soil per day resulting from the evapotranspiration of the maize and the hedgerow is shown in Table 5.1.

Table 5.1: Modification of the volumetric water content of soil per day resulting from the evapotranspiration of maize and hedgerow

Month and year	Maize[1] (vol/vol)	Hedgerow[2] (vol/vol)
October 1999	0.0022	0.0011
November 1999	0.0020	0.0010
December 1999	0.0010	0.0005
January 2000	0.0017	0.0009
February 2000	0.0027	0.0014
March 2000	0.0044	0.0022
April 2000	0.0053	0.0027
May 2000	0.0036	0.0018

[1] Calculated for a depth of 70 cm; [2] Calculated for a depth of 80 cm

The soil tension data from P1 and D2 in the treatment plots were transformed into volumetric water content (q_v) using the characteristic moisture release curve of the soil. This moisture curve was obtained from simultaneous measurements of the volumetric water content, performed with a probe using dielectric permittivity technology (Campbell Scientific, Utah, USA), and the soil tension, performed with a tensiometer gauge (H&TS Electronics Ltd, Healesville, Australia) and tensiometer tubes. The moisture release curve was calculated for the 5 to 25 cm layer of soil (Figure 5.2). The water loss by evapotranspiration by the hedgerow and the maize was added or subtracted, respectively, to the volumetric water content measured in P1 and D2 in the plots without crops (‘with hedgerow, no maize’) then reconverted into tension data. This process allows the moisture conditions to be estimated for the following combinations: ‘with hedgerow, with maize’, ‘no hedgerow, with maize’, and ‘no hedgerow, no maize’.

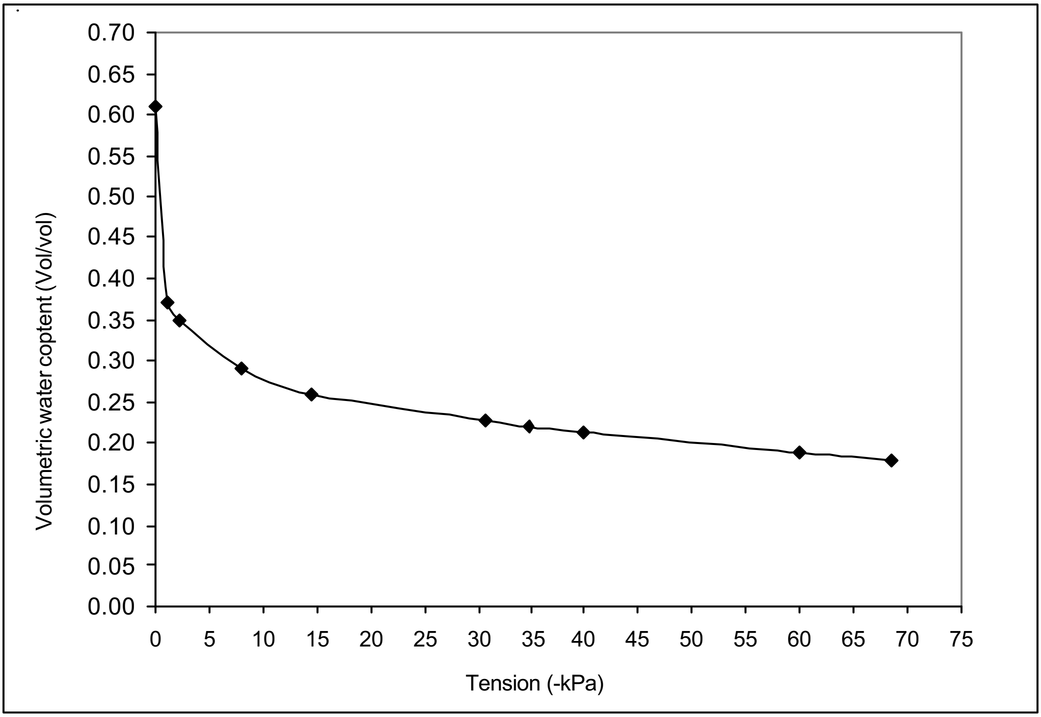

Figure 5.2: Moisture release curve (desorption) of the soil

Results

Soil moisture

The soil moisture tension measured by tensiometers at depths of 10 cm, 30 cm, 50 cm, and 70 cm for the period from 20 May 1999 to 9 January 2001 for the two treatments are shown in Figures 5.3 to 5.10.

During the monsoon, the soil tension was very low at all four depths in both treatments; this is because the soil is saturated during this period. There is more than sufficient water for crop growth, and there is no competition for water during the monsoon.

Competition for soil water only occurs during the dry season. The trend in change of soil tension was similar for both treatments at the same soil depth. The only difference was that soil tension increased slightly more rapidly with cultivation of radish than in the treatment without a crop at depths of 10 and 30 cm; at depths of 50 and 70 cm, the soil tension trend was similar. In other words, the soil moisture in the treatment with radish was slightly lower than in the treatment without radish.

The trend in soil tension was similar in both treatments. From early October, when the monsoon ceased, the soil tension increased rapidly; the highest soil tension was

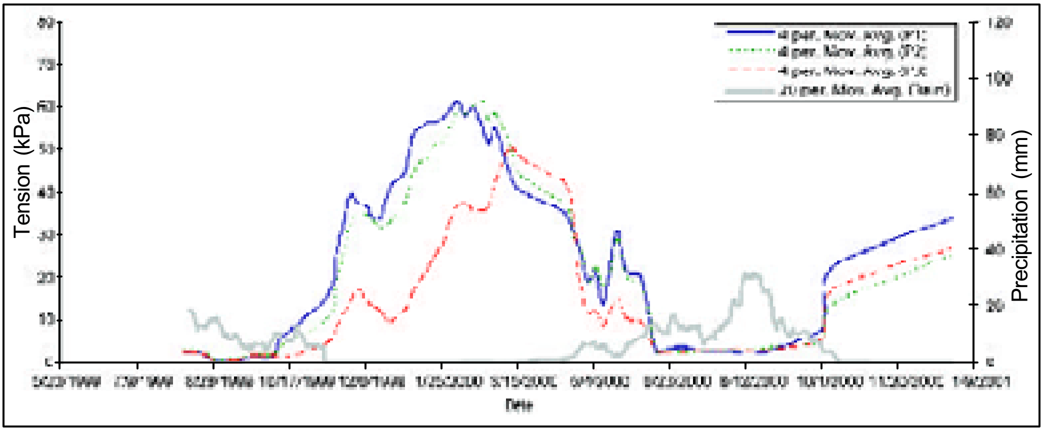

Figure 5.3: Soil tension at 10 cm, treatment without crop

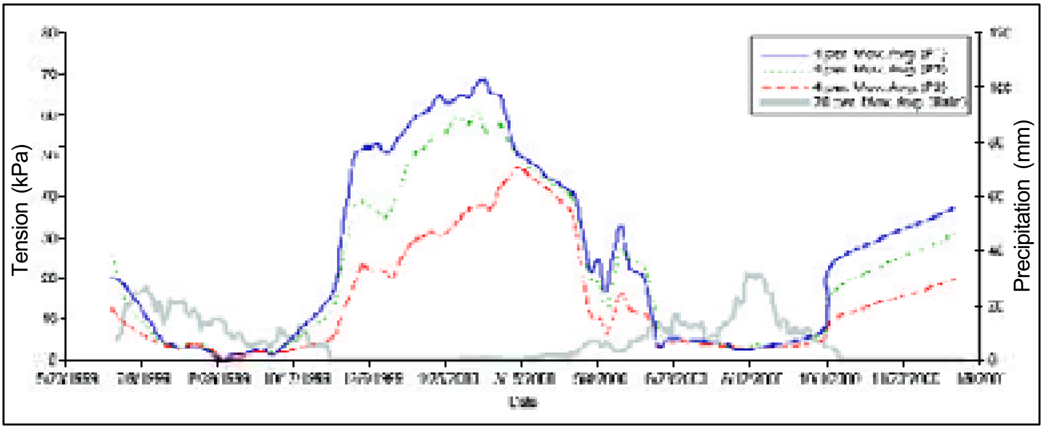

Figure 5.4: Soil tension at 10 cm, treatment with crop

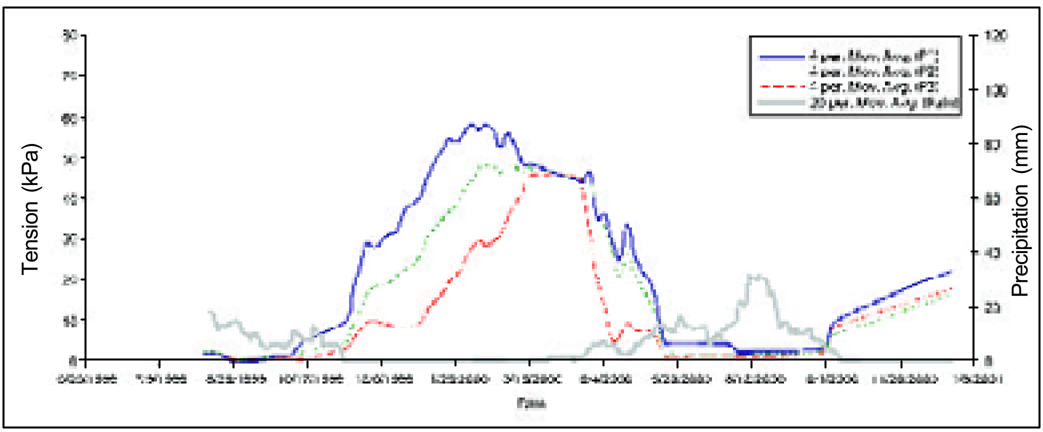

Figure 5.5: Soil tension at 30 cm, treatment without crop

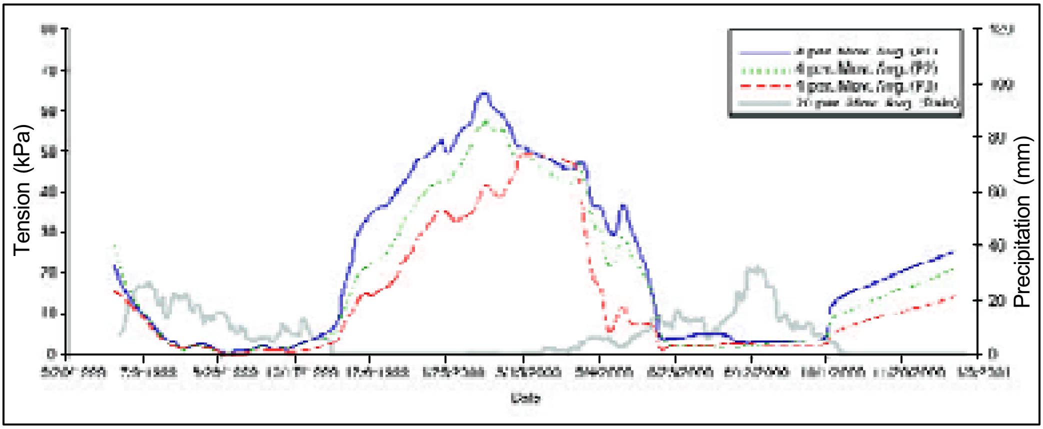

Figure 5.6: Soil tension at 30 cm, treatment with crop

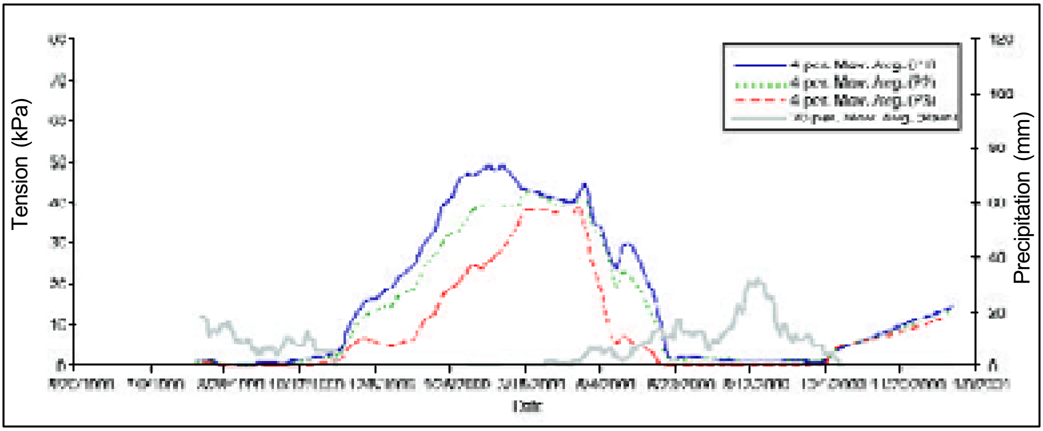

Figure 5.7: Soil tension at 50 cm, treatment without crop

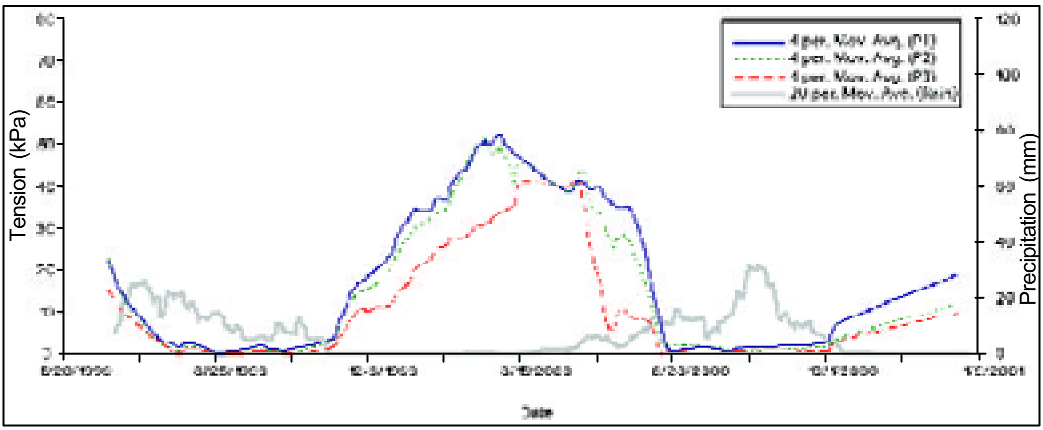

Figure 5.8: Soil tension at 50 cm, treatment with crop

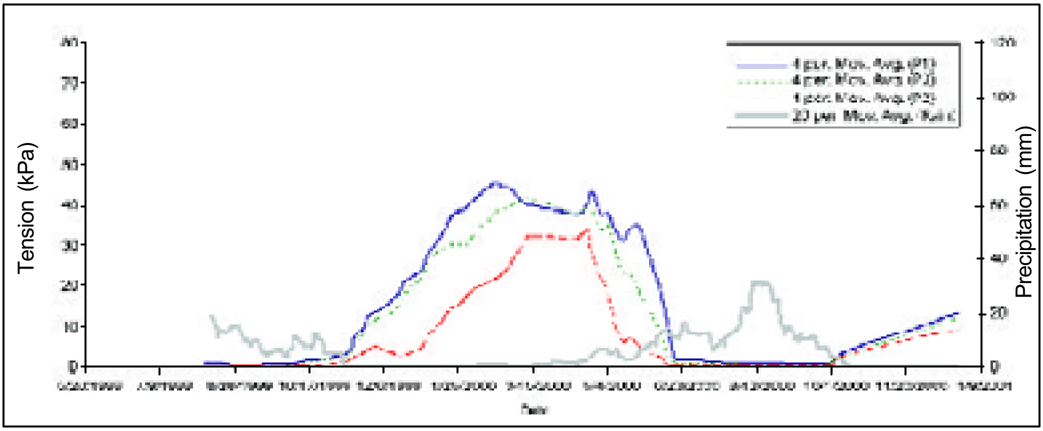

Figure 5.9: Soil tension at 70 cm, treatment without crop

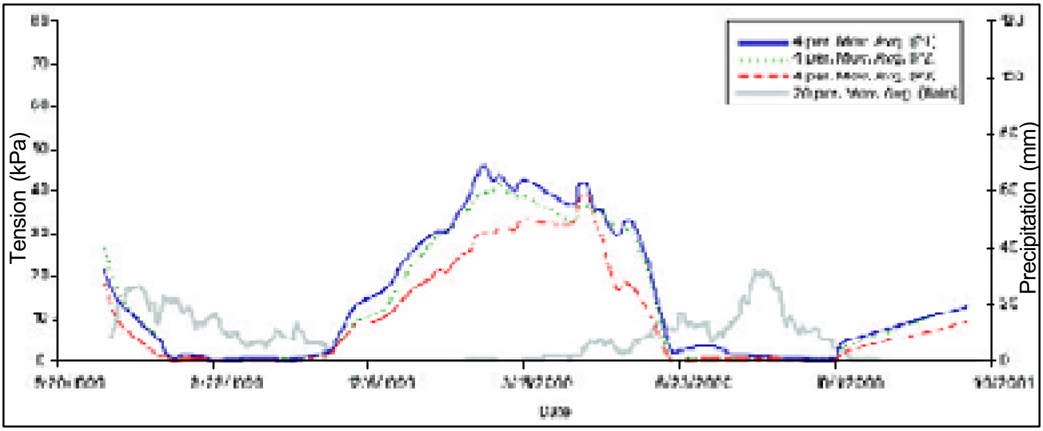

Figure 5.10: Soil tension at 70 cm, treatment with crop

observed during February and March and it decreased thereafter. Premonsoon rain led to a rapid decrease in soil tension, which was accelerated when the monsoon started properly. The deeper the soil depth, the lower was the soil tension; the increase in soil tension was not as rapid at lower depths as at a depth of 10 cm. This means that the top 10 cm soil became dry very fast, mainly because of evaporation; deeper down the soil dried more slowly.

The soil tension also decreased with increased distance from the hedgerow for all four depths in both treatments. The decrease with distance was more marked near the surface and less at greater depths.

Root competition between crops and hedgerow plants takes place in the top layer from 0-50 cm, thus the results indicate that there was competition between hedgerows and crops for soil moisture during the dry season.

There was a significant double interaction between the Position and the Depth factors (Table 5.2). This means that during the dry season the soil moisture content increases as the depth of soil increases; and the moisture content decreases closer to the hedgerow (Figures 5.3 to 5.10). These two effects are combined and produce a water distribution as shown in Figure 5.11. The moisture gradient direction, represented by the double-headed arrow, is from the topsoil close to the terrace hedge (driest) to the deep soil close to the back base of the terrace (wettest). When the rain starts, this interaction is no longer significant, as shown in Figures 5.3 to 5.10 by the convergence of the P1, P2, and P3 lines.

Table 5.2: Analysis of variance of a split block design for the tension variable

	Complete data		Dry season data		Rainy season data	
Source of variation	df[1]	F[2]	df	F	df	F
Repetition	2	2.2	2	2.1	2	2.5
Position	2	5.0	2	4.6	2	9.6*
Error A)	4		4		4	
Depth	3	24.3**	3	20.7**	3	16.51**
Time	68	33.5**	37	15.7**	30	98.6**
Error B)	141		79		66	
Position x Depth	6	9.2**	6	11.0**	6	0.7
Position x Time	136	4.8**	74	2.6**	60	5.22**
Depth x Time	204	5.4**	111	6.0**	90	2.75**
Position x Depth x Time	408	0.9	222	0.9	180	0.8
Error C)	1458		778		670	
Total	2432		1318		1113	

Note: Only the most complex interactions need to be considered in the analysis.
[1] degrees of freedom; [2] F value; *F value significant at 0.05; **F value significant at 0.01

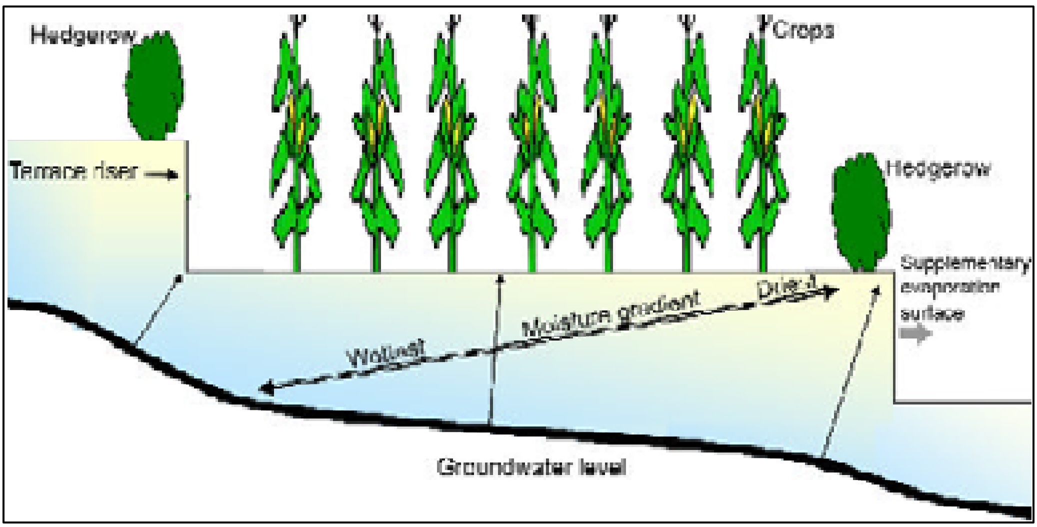

Figure 5.11: Distribution of moisture in the soil profile of a terrace during the dry season

The two other significant double interactions are between Depth and Time and Position and Time factors. They are significant for both rainy and dry seasons. These interactions indicate that the difference between the levels of Position and Depth factors are not constant over time, resulting in their convergence or divergence depending on the precipitation distribution.

Growth of maize

The maize yield for the positions C1 and C2 is shown in Table 5.3. The grain mass of maize in C1 was 91 and 48% lower than that in C2 in 1999 and 2000, respectively, and the biomass 31 and 33% lower. This indicates that the competition with the hedgerow has a negative impact on both crop biomass and crop yield. However, the statistical analysis indicated that differences in weight were not significant (Table 5.3).

Table 5.3: Fresh weight of biomass and grain for maize in 1999 and 2000

Position[1]	1999		2000	
	Biomass (kg)	Grain (kg)	Biomass (kg)	Grain (kg)
C1	7.45	1.17	7.67	1.80
C2	9.77	2.24	10.20	2.66
Probability[2]	0.216	0.084	0.076	0.144

[1] C1 was close to the hedge and C2 was far from the hedge.
[2] Probability associated with one degree of freedom for the treatment and 4 degrees of freedom for the error term.

Modelling

The evapotranspiration rates (millimetres per day) for the hedgerow and the maize are shown in Table 5.4. The evapotranspiration was 1.72 times higher for the maize than for the hedgerow (corrected values). Figure 5.12 shows that when there is a maize crop, the soil tension differences between the presence or not of a hedgerow can reach 37 kPa (in April). Drier conditions occur for about four to five weeks (mid-March to mid-April) when there is a contour hedgerow present.

Table 5.4: Climate data and evapotranspiration calculation

Godavari (altitude 1,634m)

Month	[1]T_{max}	[1]T_{min}	[2]R_s	[3]n	[4]N	n/N	[5]RH	[6]u_2	[7]ET_h	[8]ETp* Hedgerow	[9]ETp Maize	ETp_{maize} / ETp* hedgerow
	(°C)	(°C)	(W/m²)	(h)	(h)	(-)	(%)	(m/s)	(mm/d)	(mm/d)	(mm/d)	(-)
Oct. 1999	25.6	10.5	144	4.65	8.04	0.58	94	0.48	1.76	0.88	1.51	1.72
Nov. 1999	26.4	6.5	157	5.58	7.30	0.76	94	0.71	1.64	0.82	1.41	1.72
Dec. 1999	20.6	3.5	100	3.94	7.29	0.54	93	0.72	0.83	0.41	0.71	1.72
Jan. 2000	18.8	2.0	161	6.08	7.42	0.82	87	0.75	1.39	0.70	1.20	1.72
Feb. 2000	19.0	2.6	229	6.92	7.08	0.98	84	0.83	2.22	1.11	1.91	1.72
Mar. 2000	25.2	9.9	268	7.92	8.39	0.94	79	0.86	3.56	1.78	3.06	1.72
Apr. 2000	29.8	15.5	271	7.22	8.66	0.83	80	0.71	4.29	2.14	3.69	1.72
May 2000	30.1	15.5	183	4.96	9.42	0.53	90	0.56	2.90	1.45	2.49	1.72

[1] Maximum and minimum temperatures; [2] Solar radiation; [3] Duration of bright sunlight; [4] Length of day; [5] Relative humidity;
[6] Wind speed; [7] Reference evapotranspiration; [8] Corrected potential evapotranspiration for the hedgerow (by a factor of 0.50);
[9] Potential evapotranspiration for the maize crop

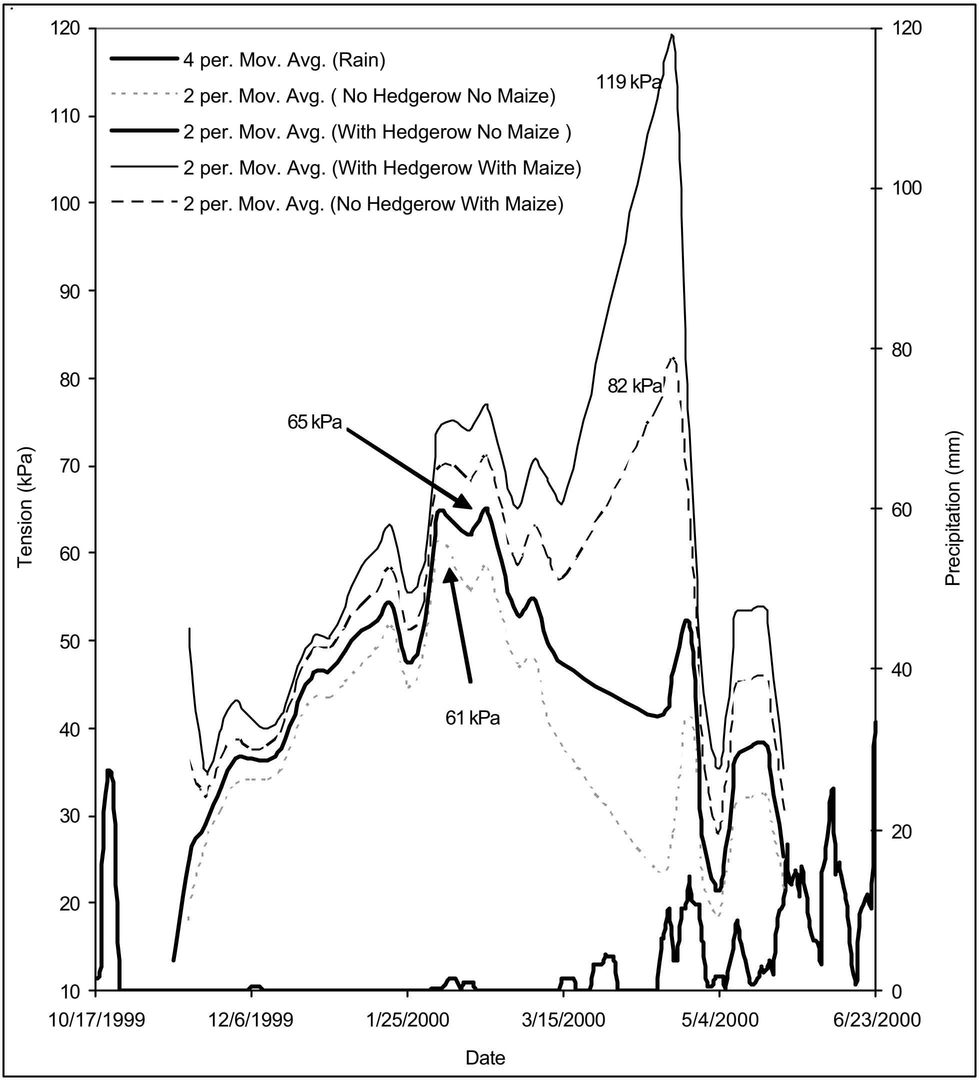

Figure 5.12: Estimated soil tension (from model calculations

Discussion

Hedgerow tree roots can compete with crop roots for available water and nutrients in the topsoil. Alley cropping experiments in semi-arid India demonstrated significant water competition between *Leucaena leucocephala* hedgerows and castor, cowpea, and sorghum crops (Singh et al. 1989). Crop yields declined from 30 to 150% of the crop at the sole of the terrace when the distance from the hedge was reduced from 5 to 0.3 m. Competition for water is often considered more important than shading effects under arid and semi-arid conditions; in the humid tropics water is not as limiting as nutrients in the soil.

The present study of soil tensions in a bioterrace showed that the moisture distribution was not uniform. The practical implication is that growing crops close to the edge of the terrace could be affected by prevailing dry conditions. In this experiment, the maize growth was not significantly affected by its location on the terrace. This might be because of the small number of repetitions, which meant that there were only four degrees of freedom for the error term. However, the absence of a significant effect on maize growth is more likely to be due to the excess of water available to the crop during the rainy season. This was shown by the soil tension distribution which showed no significant differences for the soil tension between the three positions on the terrace during the maize growing period. Further, when the situation for water is considered together with the results for soil nutrient research (Chapter 4), it becomes clear that the competition for water between hedgerows and maize might be sidelined by the higher nutrient conditions closer to the hedgerows.

The moisture gradient during the dry season can be attributed, in part, to the particular morphology resulting from the terracing (Figure 5.11). The distance between the groundwater and the topsoil increases closer to the edge of the terrace, and the terrace riser provides a supplementary evaporation surface which also enhances the moisture gradient in the terrace. The other factor that possibly enhances the moisture gradient is the presence of the hedgerow. One criterion for hedgerow species selection is that the root system is deeply anchored in the soil to assure nutrient cycling from the deep soil to the surface and avoid water competition with crops. Excavation of *Alnus nepalensis* plants showed that the hedgerow's roots explore 40% of the terrace surface at a depth of 0.80m. The results of the modelling exercise (Figure 5.12) indicate that the hedgerow enhances the soil tension on this portion of the bioterrace. The differences between the curves with and without hedgerow increase progressively to reach a peak around the 20th of April when there is a hypothetical maize crop, and around the 20th of February for the bare soil. This is explained by a high evapotranspiration demand during March and April, a period when the sporadic rainfall is not sufficient to reduce the soil tension in the way it does for bare soil. Another obvious difference is the relative impact of the hedgerow on the soil tension depending on the presence of a crop. This is attributed to the characteristic form of the moisture release curve (Figure 5.2), which shows that the extraction of water produces a more marked increase of the soil tension (created by the maize evapotranspiration) under dry conditions than under wet conditions.

Since the hedgerow contributes to enhancing the moisture gradient on the bioterrace, it is possible that competition could take place between the hedgerow and the crop. Kabat and Beekma (1994) indicate that plant growth begins to be limited by the soil moisture conditions at between 40 and 100 kPa of tension. As our results were from estimations, it is hazardous to predict that yields will be reduced. A specific field experiment is needed for this.

An experiment carried out by Singh et al. (1989) indicated that root and light competition between hedgerows and crops could lead to a reduction in yield of sorghum and cowpea by 70%. Their study also indicated that root competition is greater than light competition, in that sorghum and cowpea adjacent to the hedgerows experienced intense shading, but with a root barrier in place yielded almost the same as the crops distant from the hedgerow. Experiments have demonstrated that competition for soil moisture is strong and leads to a reduction in crop yield (Singh et al. 1989; Ong and Black 1994). In our study we also observed a reduction in the maize crop closer to the hedgerow, but there was an increase in the fresh radish yield (Chapter 4).

The effect of hedgerows on soil moisture is different in different regions. One study found that soil moisture at 0-5 cm depth was higher in the vicinity of hedgerows than in non-agroforestry (hedgerow) systems, which was attributed to the effect of shade and reduced soil-moisture evaporation (Lal 1989). However, this study was over a rather short period and a long term study is needed for a concrete conclusion.

Conclusion

This experiment clearly demonstrated the existence of a moisture gradient on the terrace surface during the dry season. This gradient disappeared during the rainy season. The moisture gradient was attributed both to the particular morphology resulting from the terracing and to the presence of the hedgerow. The modelling exercise showed that an *Alnus nepalensis* hedgerow increased the moisture gradient on 40% of the terrace. Further studies should be performed to investigate the potential effect of introducing a contour hedgerow on the water available to the crop and the effect on the yield.

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