WATER MANAGEMENT AND MINERAL NUTRITION OF BAMBOO

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1. Site

The agronomic practices of irrigation and fertilization on performance of *Phyllostachys pubescens* (often know as Moso bamboo) were tested for four years at Durnford Dart's farm at Belli Park. Representative meteorological and soil data for the site are presented in Table 1 and 2.

Table 1 Meteorological data (twenty-five year averages) from Nambour, 25 km south of Belli Park

Month	Mean monthly precipitation (mm)	Mean monthly evaporation (mm)	Mean maximum temperature (°C)	Mean minimum temperature (°C)	Mean daily hours of sunshine (h)
Jan	293	176	28.5	19.1	6.5
Feb	276	133	28.1	19.3	6.0
Mar	260	129	27.4	18.1	6.2
Apr	137	115	25.8	15.0	7.0
May	111	87	23.1	11.4	6.4
Jun	84	77	21.4	9.2	6.5
Jul	93	83	20.7	6.9	7.3
Aug	48	101	22.1	7.5	7.6
Sep	48	123	24.1	10.0	7.7
Oct	114	153	26.0	13.4	7.7
Nov	155	164	27.4	16.1	8.0
Dec	178	185	28.6	17.8	7.4
Annual average	**1797**	**1524**	**25.3**	**13.7**	**7.0**

Table 2 Soil chemical attributes at Belli Park in 1990

Attribute	Value	Attribute	Value
pH ($CaCl_2$)	4.3	Ca (meq/100g)	1.50
CEC (meq/100g)	4.7	Mg (meq/100g)	1.05
P (Bray-mg/kg)	3.0	Al (meq/100g)	1.30

Experimental plots were superimposed in October 1994 on established *P. pubescens* stands. In November 1990, 18-month-old seedlings of *P. pubescens* were planted at six-meter intervals along rows seven meters apart. Blood and bone fertilizer was applied at planting and 25:5:14.1 N:P:K fertilizer at 1,000 kg/ha was applied at six-month intervals prior to the beginning of the experiment. The *P. pubescens* stand was irrigated by overhead impact sprinklers along lines placed between rows.

2. Materials and Methods

Four years after planting of the 'runner' bamboo stand the experimental area was split into two irrigation blocks. Both high-irrigation and low-irrigation blocks were fed by the same main line. They had regular (i.e. farmer determined) irrigation, but the high irrigation block had an additional irrigation line of rotary sprinklers along each row. Therefore, about 50 % more water was applied to plots in the high-irrigation treatment. Each irrigation block was split into four replicate rows, with three plots along each row randomly assigned one of three fertilizer treatments: the farmer's rate (250:50:141 kg/ha N:P:K), 1.5 and 2 times the farmer's rate. Figure 1 shows water application rates in both irrigation rates in 1996.

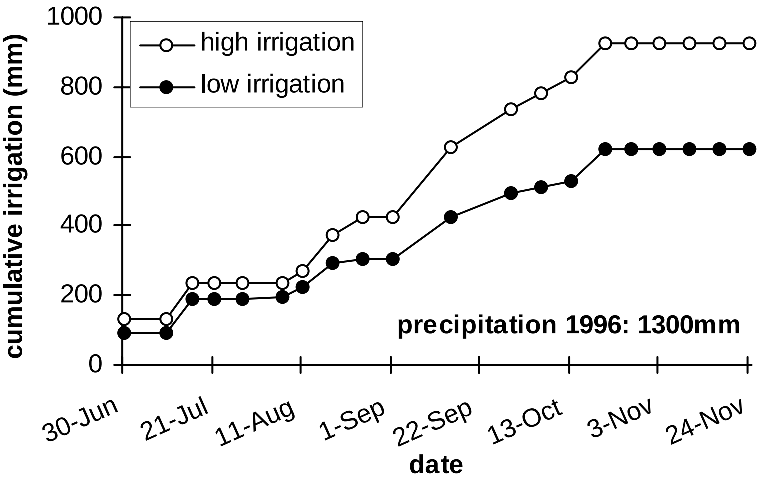

Fig. 1 Irrigation rates and precipitation in the *P. pubescens* irrigation-and-fertilizer trial at Belli Park in 1996

Fertilizer treatments were applied in 1995 and 1996, but in 1997 the low (farmer's) rate was used for all treatments. Tensiometers at 30 cm and 60 cm depths were installed in two plots (the highest fertilizer rates in both high and low irrigation) and were read periodically from November 1994. Water-stress indexes were calculated from those data (30-cm soil depth) using the formula:

$$T_m = \frac{\sum_{i=0}^{m}(d_{i+1} - d_i)t_i}{\sum_{i=0}^{m}(d_{i+1} - d_i)} \qquad \text{[kPa]}$$

where: T_m is the water-stress index, i represents a single time of tension measurement, m represents the total number of readings, d represents the Julian day of the year when a reading was made, (d_{i+1}-d_i) is the time interval in days between successive readings, and t_i is the moisture tension at a single time.

Leaf samples (youngest fully expanded) from each plot were analyzed for mineral content at the start of the experiment in 1994, and in 1995 and 1996. Soil samples (30-cm depth) were analyzed in 1994 and 1996. Weekly counts of new shoots that emerged during the shooting season (late winter to early spring 1994 and 1995) and their diameters (at soil level) were taken in a 1-meter-wide transect within the centre of each plot. Yield was recorded in 1996 and 1997 as number of shoots, shoot weight and shoot diameter in each plot. Main effects of fertilizer and irrigation, and their interaction were analyzed with ANOVA techniques.

3. Results and Discussion

In 1994, the number of new culms emerging during the shooting season tended to be greater (statistically not significant, *P* = 0.26) in the high-irrigation treatment (Figure 2, top). No influence of fertilization on shoot emergence could be determined in that season (Figure 2, bottom), neither across the average of irrigation rates (error bars), nor within individual irrigation treatments (*P* values).

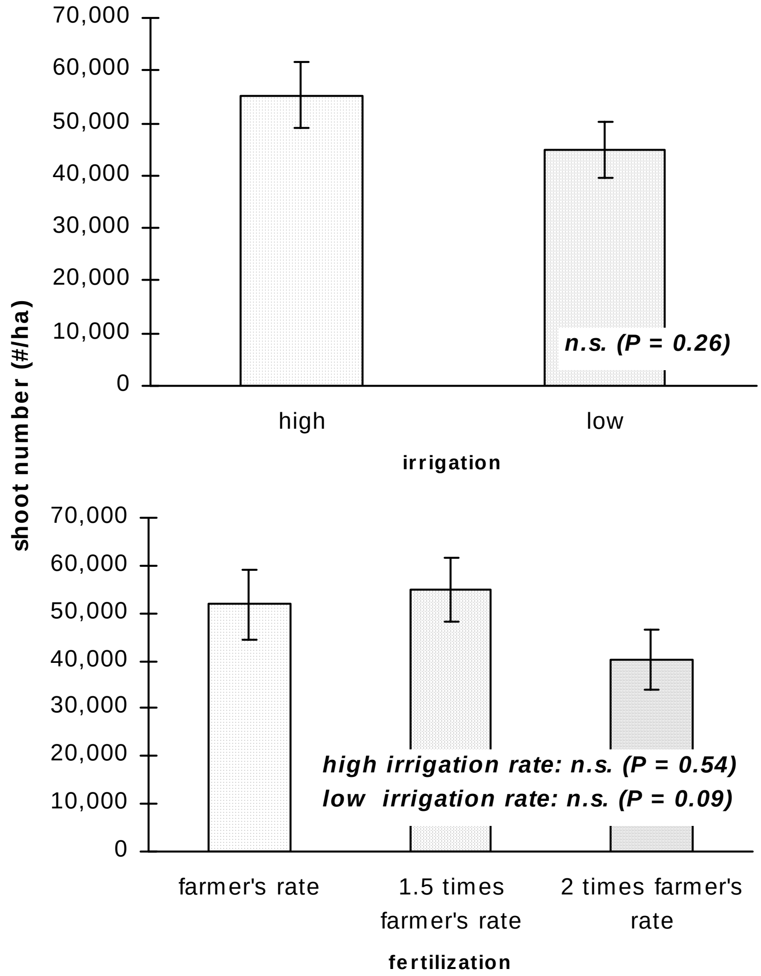

Fig. 2 Effect of (top) irrigation and (bottom) fertilization on shoot production of *P. pubescens* at Belli Park in 1994 (error bars indicate standard errors, P-values significance levels of LSD means separation tests)

In 1995, significantly more shoots were produced in the low irrigation treatment (Figure 3, top), but fertilizer treatment exerted no effect on shoot production in that year (Figure 3, bottom). However, the fertilizer effect was greater in the high-irrigation treatment compared with the low-irrigation treatment as indicated by a lower *P* value (0.32 vs. 0.68). In contrast to the lower number of shoots produced in the high-irrigation treatment (Figure 4, top), those shoots were significantly greater as indicated by shoot diameter (Figure 4, bottom). The shoot-size effect was stronger than the shoot-count effect (*P* values: 0.01 vs.0.04).

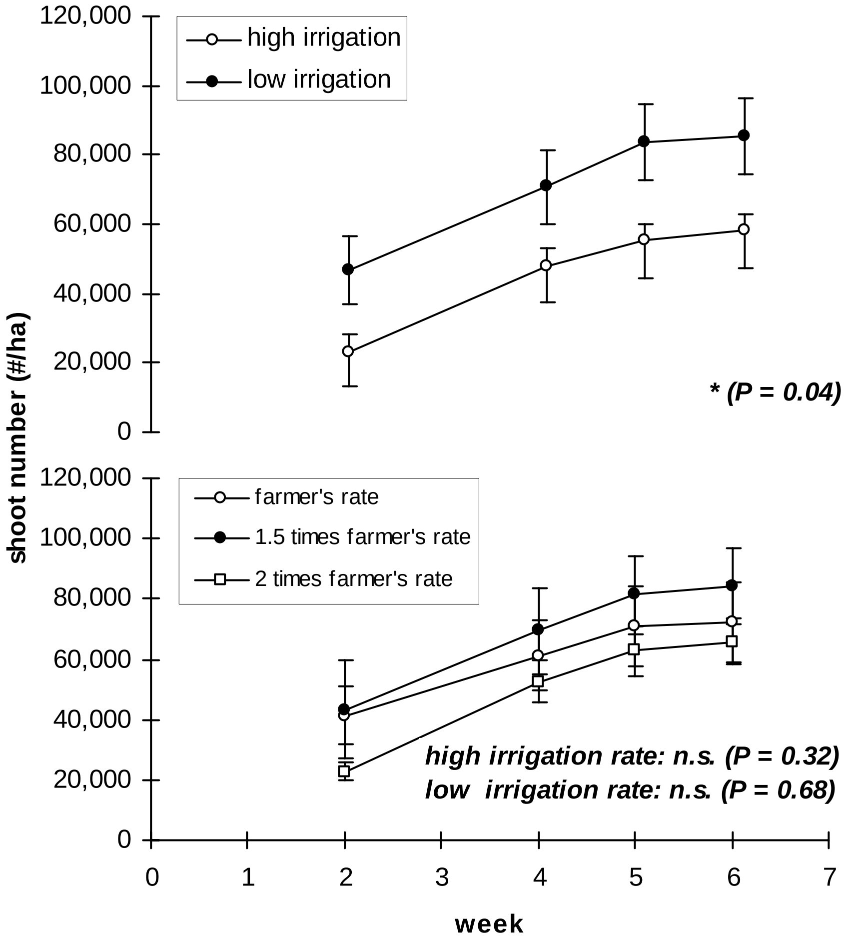

Fig. 3 Effect of (top) irrigation and (bottom) fertilization on shoot production of *P. pubescens* at Belli Park in 1995

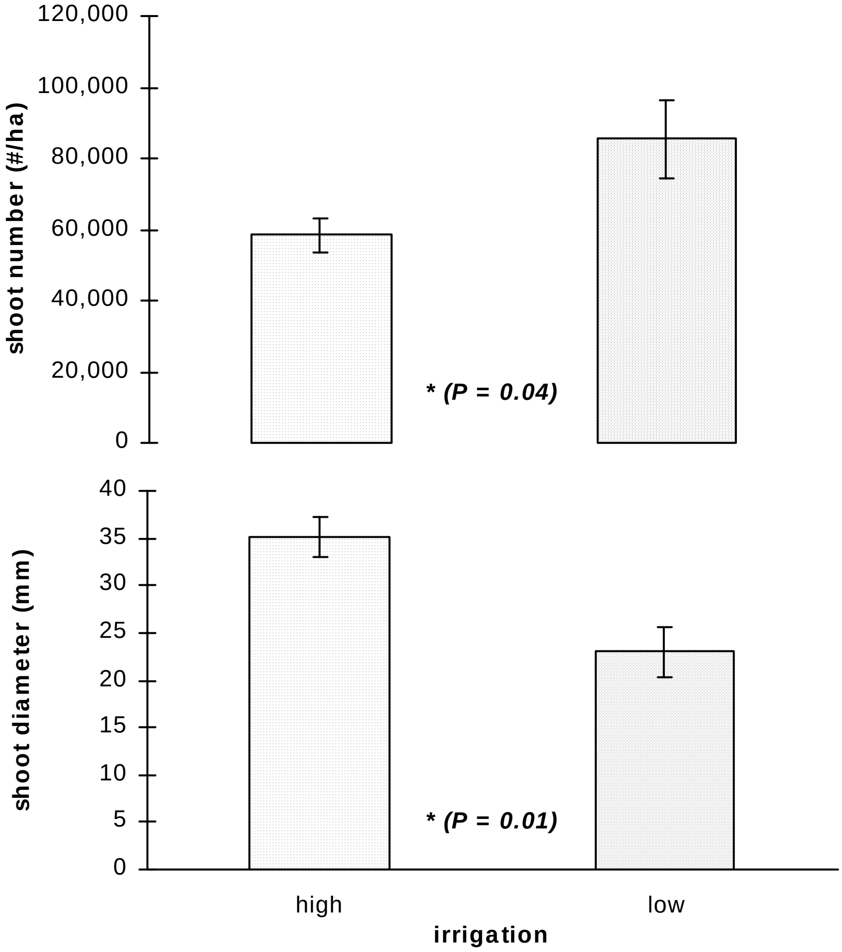

Fig. 4 Effect of high irrigation on (top) shoot number and (bottom) shoot diameter of *P. pubescens* at Belli Park in 1995.

In 1996, shoots were harvested for the first time. Cumulative yield was greater in the high-irrigation treatment (Figure 5, top). Although more yield was produced when the fertilizer rate was doubled, this effect was statistically not significant as indicated by *P* values (Figure 5, bottom). However, the influence of fertilizer rate on yields was greater under the high irrigation rate (P = 0.17; figure 6, top) than under the low irrigation rate (P = 0.91; figure 2.6, bottom). Figure 7 shows that irrigation was primarily important for increasing shoot yields in 1996: there was no response to fertilization when irrigation rates were low but shoot yields under the greater fertilizer rate were almost doubled when more irrigation was applied.

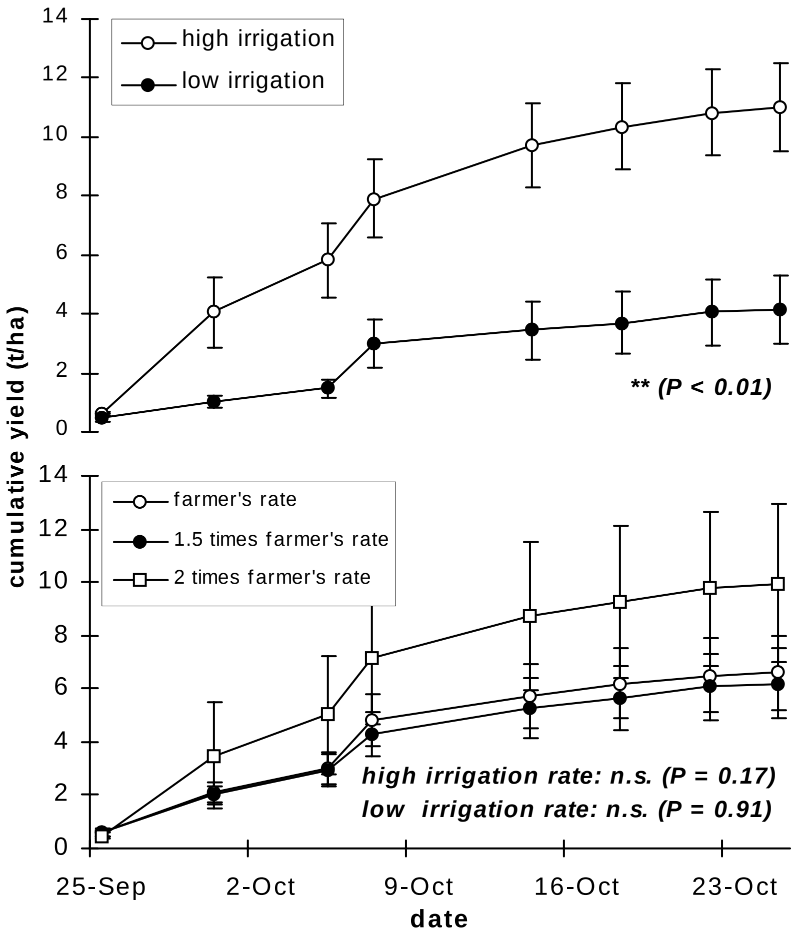

Fig. 5 Effect of (top) irrigation and (bottom) fertilization of cumulative yield of *P. pubescens* at Belli Park in 1996.

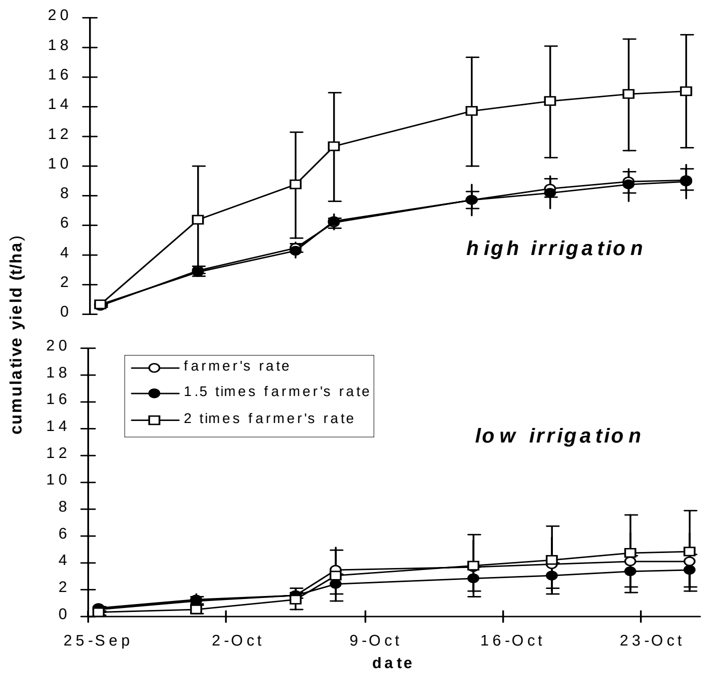

Fig. 6 Effect of fertilization under (top) high irrigation and (bottom) low irrigation on cumulative yield *of P. pubescens* at Belli Park in 1996.

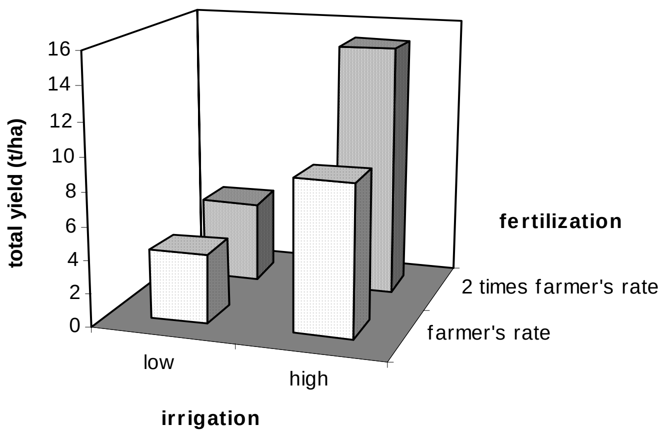

Fig. 7 Effect of irrigation and fertilization on total yields of *P. pubescens* at Belli Park in 1996

All yield parameters in bamboo were improved by higher irrigation in the 1996 season (Figure 8): shoot number was significantly greater (top), while shoot diameter (middle) and shoot weight (bottom) tended to be greater.

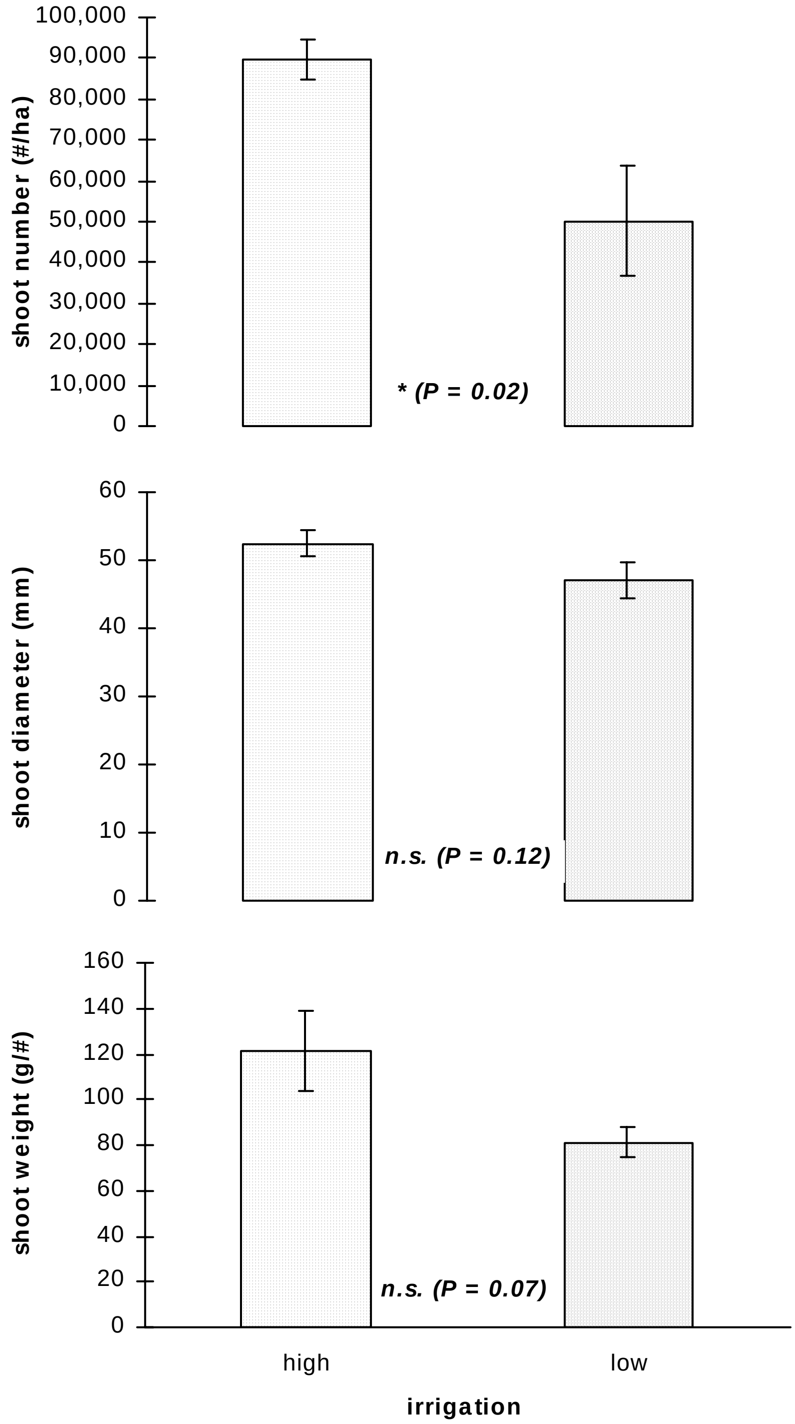

Fig. 8 Effect of irrigation on (top) number, (middle) diameter and (bottom) weight of harvested shoots of *P. pubescens* at Belli Park in 1996

The influence of irrigation on bamboo performance was highly significant in 1997 (Figure 9, top). The standard (farmer's) fertilizer rate was applied to all plots and no effect of previous fertilizer application could be measured (Figure 9, bottom).

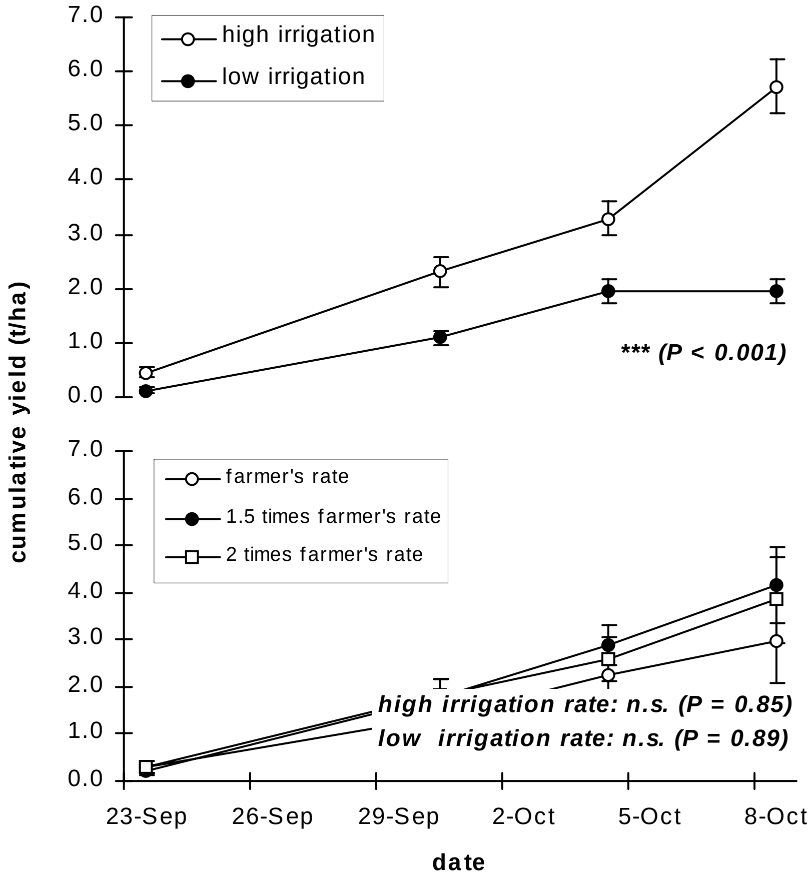

Fig. 9 Effect of (top) irrigation and (bottom) fertilization on cumulative yield of *P. pubescens* at Belli Park in 1997

Yield parameters were significantly improved by the greater irrigation rate (Figure 10).

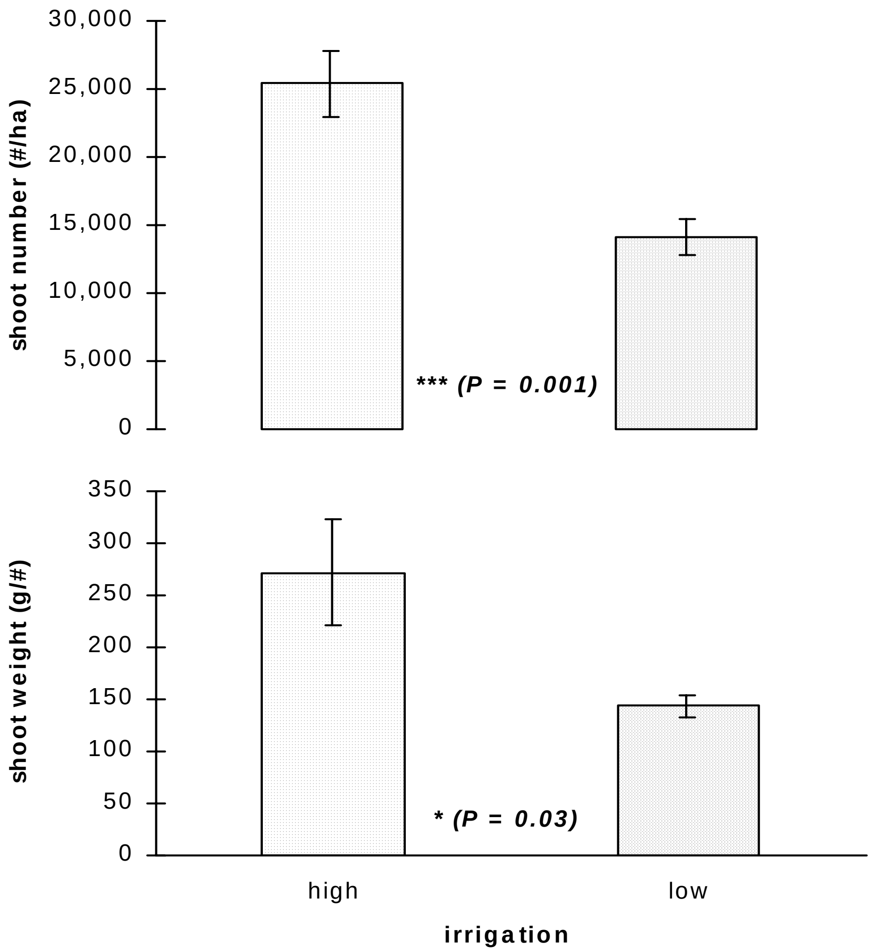

Fig. 10 Effect of irrigation on (top) number and (bottom) weight of harvested shoots *of P. pubescens* at Belli Park in 1997

To explain treatment effects on bamboo performance, a simple growth model was applied to the data collected (Figure 11).

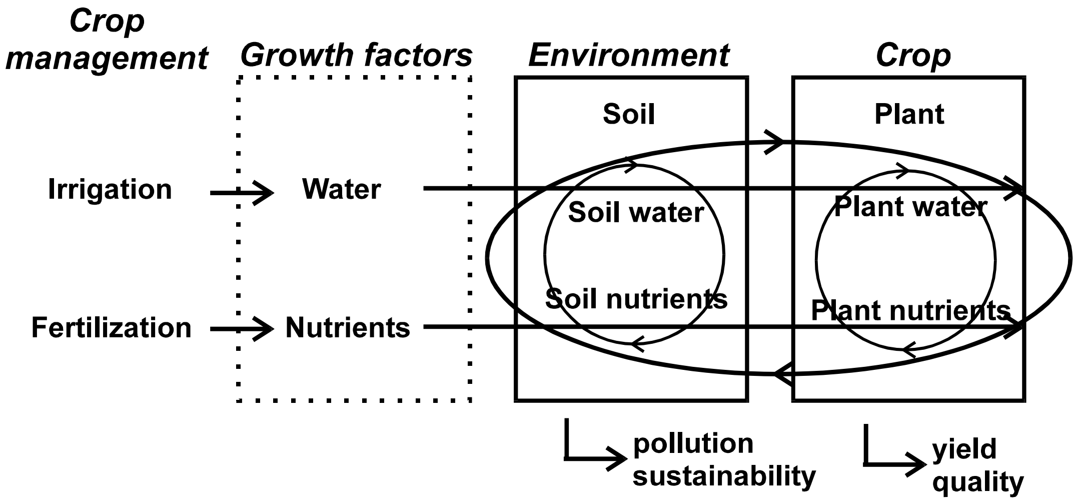

Fig. 11. Simplified relationship between crop and environment, and influence of growth factors.

By applying crop-management techniques of irrigation and fertilization, the growth factors ‘water’ and ‘nutrients’ are modified. This affects their intensity in the environment and in the crop. The intensity of individual growth factors and their interactions determine growth of plants (ie, the ‘*Mitscherlich*-model’). To measure the effects of irrigation and fertilization on crop productivity and the environment, measures for water and nutrients in the soil-plant system were developed.

‘Soil water’ was measured as soil moisture tension by tensiometers and ‘plant water’ as leaf water potential by a *Scholander* pressure bomb. The effects of soil-water availability on plant growth were estimated by calculating water stress indices and relating them to bamboo yield. ‘Soil and plant nutrients’ were measured by soil and plant analyses.

Soil moisture tension was usually greater in the low-irrigation treatment throughout the season in 1997 (Figure 12, top). Since soil moisture was better controlled under high irrigation, ‘water stress’ (ie, the water stress index referred to in the Materials and Methods) was lower in this treatment (Figure 12, bottom). Water-stress indices at the end of the season were significantly related to crop yield (Figure 13).

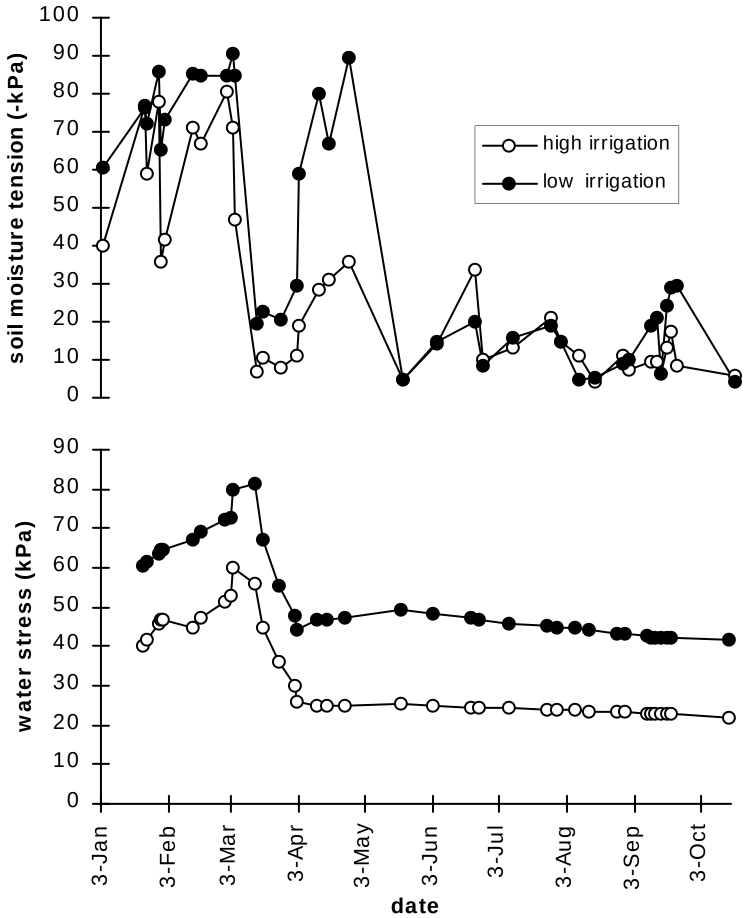

Fig. 12 Effect of irrigation levels on soil moisture tension (top) and water stress (bottom) in *P. pubescens* at Belli Park in 1997

Better supply of soil water was reflected in plant water status: although statistically not significant, leaf water potential tended to be lower in the high-irrigation plots (Figure 14).

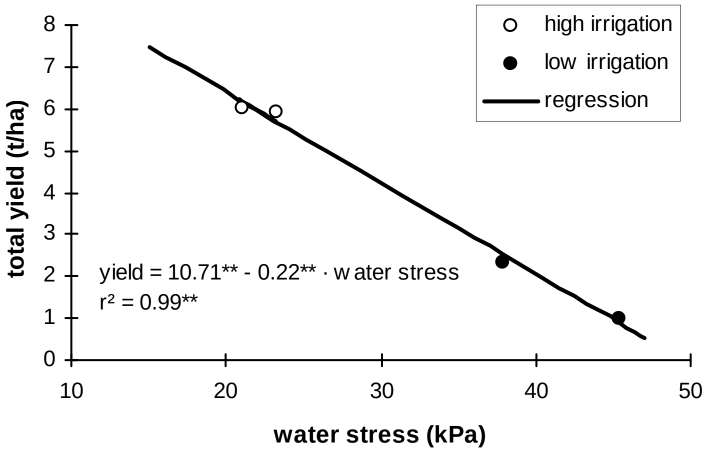

Fig. 13 Regression of water-stress indices on yields *of P. pubescens* at Belli Park in 1997

Prior to application of the fertilizer treatments in 1994, leaf and soil samples from established plantations (Table 3) revealed high levels of manganese most likely associated with the low pH (4.9-5.3) and seasonal water logging. Leaf samples from green *P. pubescens* were low in P, K and B. Yellow leaves from plants in a waterlogged area showed slightly lower levels of these elements. Soil sampled from around those plants showed adequate inorganic N, but low P and B levels. Lime at the rate of 600 kg/ha was applied uniformly over the whole experimental area for *P. pubescens* in August 1995. By April 1996 treatment averages for pH ranged from 4.82 to 5.35.

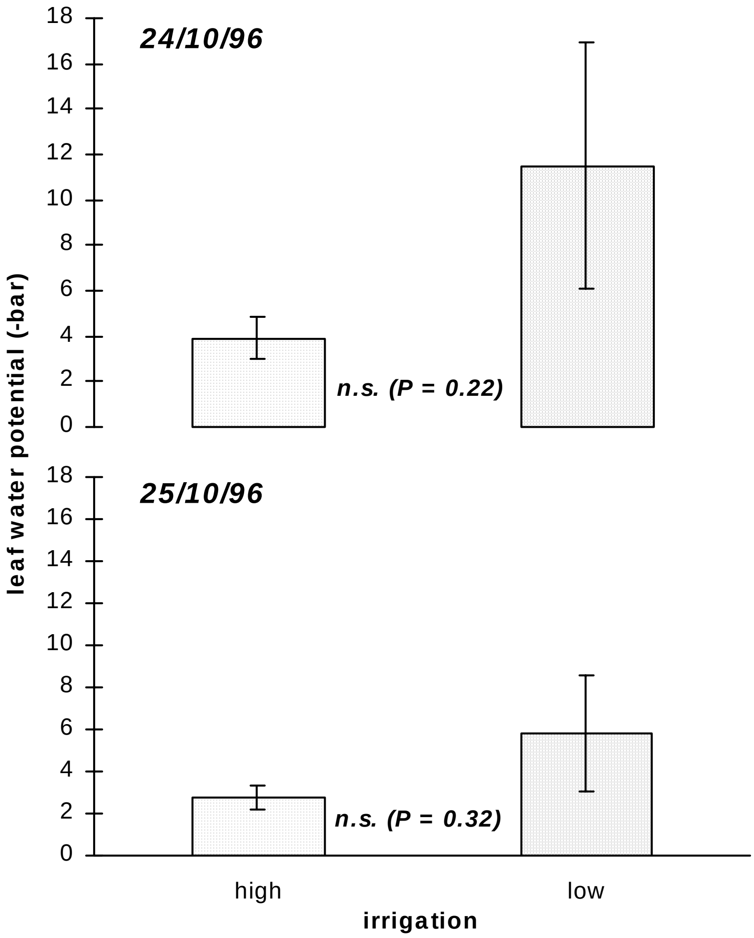

Fig. 14 Effect of irrigation levels on leaf water potential on two occasions in *P. pubescens* at Belli Park in 1996

Table 3 Leaf and soil characteristics of *P. pubescens* at Belli Park in 1994

Attribute	Green plant	Yellow plant
<u>Soil</u>		
Organic C (%)	2.7	1.8
$N0_3$-N (ppm)	20.0	33.3
S (ppm)	18	11
P (ppm)	18	36
Mn (ppm)	46	41
K (meq/100g)	0.30	0.42
Ca (meq/100g)	5.50	1.84
PH	5.3	4.9
EC (dS/n)	1.0	0.9
<u>Leaf</u>		
N (%)	2.60	2.24
S (%)	0.24	0.20
P (%)	0.14	0.12
K (%)	0.72	0.57
Mn (ppm)	1423	1520
B (ppm)	10	13

Total soil N and C were not significantly influenced by fertilizer rates in 1996. Leaf samples collected in 1995 in the high-irrigation plots showed an increase in total nitrogen and carbon with greater fertilizer rates (Figure 15). In 1996, this trend was statistically significant for N, but not for C.

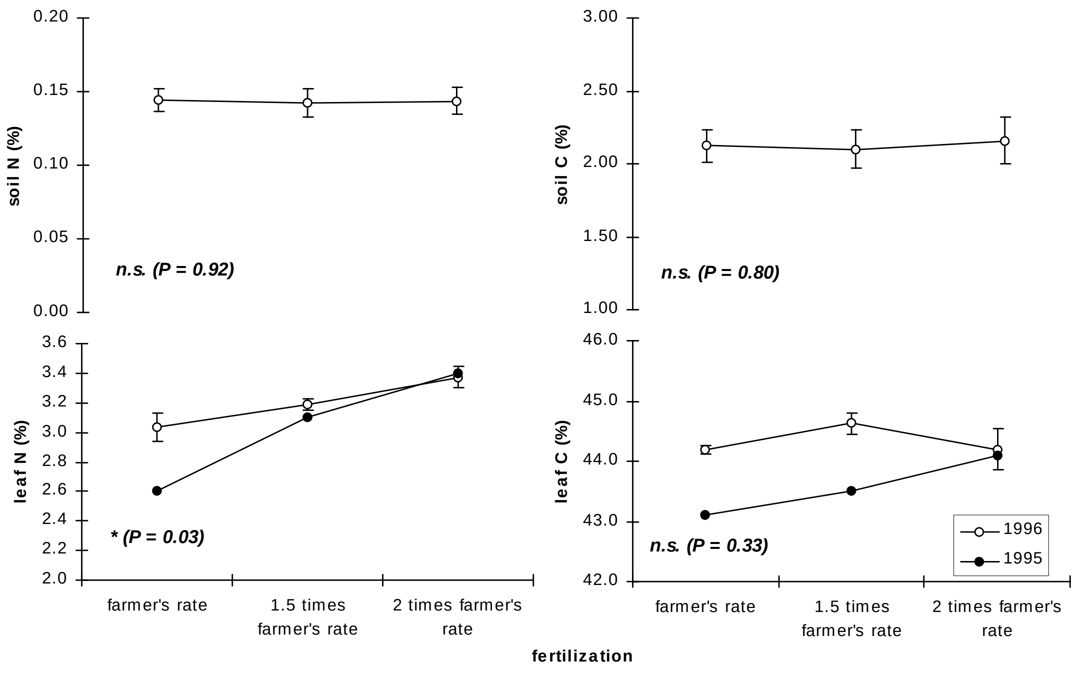

Fig. 15 Effect of fertilization on (left) nitrogen and (right) carbon in (top) soil and (bottom) plant in *P. pubescens* (high irrigation) at Belli Park in 1995/96

At the higher irrigation rate, soil nitrogen and carbon was significantly improved, whereas pH and electric conductivity were not significantly affected (Figure 16).

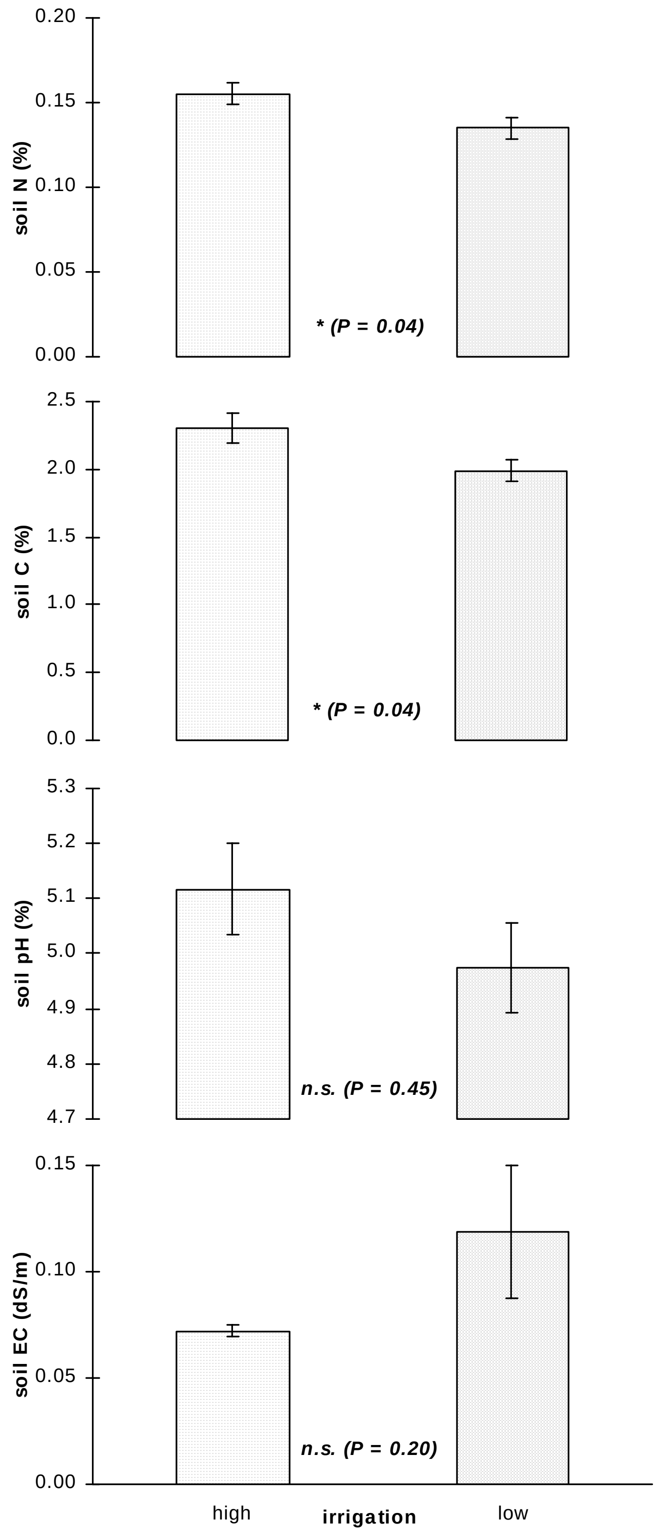

Fig. 16 Effect of irrigation on soil parameters in *P. pubescens* at Belli Park in 1996

There was no relationship between total soil nitrogen and bamboo yield for *P. pubescens* cultivated with low irrigation (Fig. 17). However, bamboo yields tended to be greater with more soil nitrogen under high-irrigation conditions.

According to *Mitscherlich*, a growth factor, which is below its critical level, determines the growth

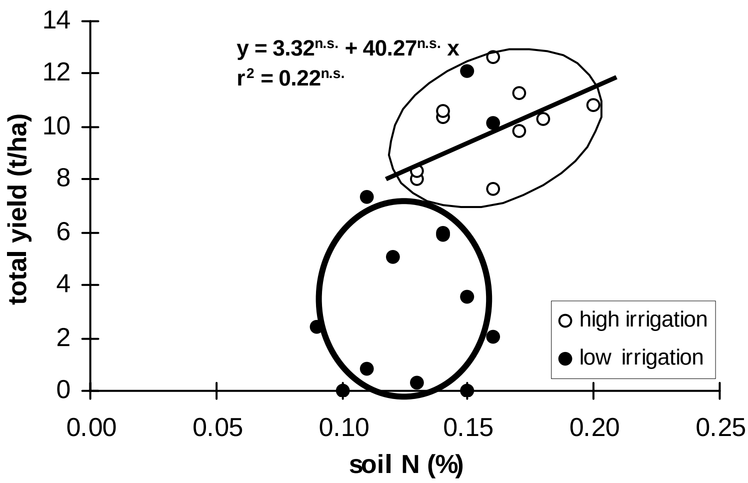

Fig. 17 Effect of total soil nitrogen on *P. pubescens* yield at Belli Park in 1996

of a plant. Only by elevating this 'minimum-factor' further to its optimum, growth can be improved. Managing growth factors other than the particular minimum-factor will have no effect, or limiting, on growth. However, if one growth factor is optimized, another factor may become the minimizing, or limiting, element for growth and so on.

'Water' appeared as the most important growth factor for bamboo in this experiment. At early growth stages, bamboo growth only tended to be improved by the high-irrigation treatment. However, this effect gained importance with crop age. In 1994, slightly more shoots were developed under high-irrigation conditions. In 1995, less shoots emerged, but their greater size overcompensated for the smaller number. High irrigation improved yields in 1996 and 1997 with increasing distinctness ($P < 0.01$ and $P < 0.001$). The same was true for all other yield parameters (number and size of shoots). By applying more irrigation, water stress in bamboo was alleviated as indicated by water-stress indices and leaf water potential. Water stress caused by deficient soil water conditions explained the greater part of variations in bamboo yield in 1997 (Figure 13). In contrast, Table 3 shows the detrimental effect of excessive soil water on nutrient uptake of bamboo. This indicates that bamboo requires water in large, but not excessive, quantities. Higher irrigation improved soil parameters (Figure 16). This could be due to greater nutrient cycling under those conditions: irrigation improved crop growth and thereby increased return of organic material to the soil (i.e. leaf drop).

'Nutrients' were only a secondary growth factor for bamboo since fertilizer application had no effect on bamboo growth except when irrigation was applied at the higher rate. This one-side interaction was particularly pronounced in 1996: under low irrigation the greater fertilizer rate did not improve yield, but under high irrigation yields almost doubled (Figure 7). Figure 17 shows that bamboo responded favourably to greater soil-nutrient contents only under high-irrigation conditions. Under those conditions, fertilizer application significantly increased the plant nutrient status (plant N) but had no effect on the soil nutrient level (soil N, figure 15). This indicates that available nutrients were effectively absorbed by bamboo under high-irrigation conditions. On the other hand, excessive soil water hindered uptake of soil nutrients as stated above. Since rates of biomass production were much lower when less water was applied, it can be assumed that the extra nutrients applied in the high-fertilizer treatment could not be absorbed by bamboo and were consequently lost, e.g. through leaching. In contrast to irrigation, which had a multiplying long-term effect on bamboo growth, effects of fertilizer were only short-lived: differential fertilizer rates in 1994, 1995 and 1996 exerted no effect on yields in 1997 when only the standard fertilizer rate was applied to all plots.

To sum up, successful cultivation of *P. pubescens* bamboo in the studied environment primarily depends on sufficient, yet not excessive, supply of water (approximately > 2000 mm/year). In areas where natural supply of water (i.e. precipitation, underground supply) does not match the high demand of bamboo, the extra quantities must be supplied by irrigation for achievement of high yields. This will have a multiplying effect on yield over time. Under such optimal water management, the yield potential of Moso bamboo may be 15 tons per hectare and year or even higher. This potential requires approximately more than 400 to 500 kg N per hectare and year. Fertilizer application in one season seems to have no residual effect on crop growth in subsequent years. Therefore, fertilizer must be continuously applied to bamboo at a rate sufficiently high to sustain a yield potential that is governed by water availability. The greater productivity of bamboo under high-input conditions (high irrigation and fertilizer) may also curb pollution of the environment and thereby maintain, or even improve, sustainability of the cultivation area.