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# GROWTH, BIOMASS ESTIMATIONS AND FUEL QUALITY EVALUATION OF COPPICE PLANTS OF *PROSOPIS JULIFLORA* ON SODIC SOIL SITE

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**GOEL, V. L. & BEHL, H. M. 2000. Growth, biomass estimations and fuel quality evaluation of coppice plants of *Prosopis juliflora* on sodic soil site.** A 3.5-y-old coppice trial of *Prosopis juliflora* was evaluated for wood fuel production on a highly alkaline soil site (pH > 8.7). Initially coppice plants showed emergence of 11.7 ± 5.1 sprouts per stump followed by dominance of 3.7± 0.7 shoots per stump after 42 months of growth. Dominant shoots attained an average height of 470 ± 133 cm and a diameter of 3.4 ± 1.5 cm at 50 cm from ground level. Linear regression equation [$y = a + b(nd^2h)$, measurement of height and diameter of the most dominant shoot and counting number of coppice shoots per plant] was found to be the best predictor of biomass because of high correlation coefficient and significance of regression coefficients ($p < 0.001$, $p < 0.01$). Equations using height or diameter alone had relatively poor functional correlation. At the age of 3.5 y, coppice plants produced a total of 82.7 t $ha^{-1}$ green biomass with nearly 90% biomass allocation to stems (43.2 t $ha^{-1}$) and branch wood (31.2 t $ha^{-1}$). Leaves (8.32 t $ha^{-1}$) contributed marginally. Accordingly, oven dry mass of stem wood (23.2 t $ha^{-1}$) was maximum followed by branch wood (18.7 t $ha^{-1}$) and leaves (2.15 t $ha^{-1}$) respectively. Fuel quality of coppice plants assessed on the basis of wood fuel value index (607 ± 65.7 to 1518 ± 81.8) and biomass–ash ratio (29 to 37) varied greatly depending on shoot thickness. The study shows the potential of coppice system in *P. juliflora* to obtain quality fuelwood under short rotation harvest (<4 y) on sub-standard soil sites.

Key words: *Prosopis juliflora* - sodic soils - coppice growth - biomass assessment - fuel quality evaluation

**GOEL, V.L. & BEHL, H. M. 2000. Anggaran pertumbuhan, biojisim dan penilaian mutu bahan api daripada pokok-pokok kopis bagi *Prosopis juliflora* di tapak tanah sodik.** Satu percubaan kopis bagi *Prosopis juliflora* berumur 3.5 tahun dinilai bagi pengeluaran kayu api di tapak tanah beralkali tinggi (pH > 8.7). Pada awalnya, pokok kopis menunjukkan kemunculan sebanyak 11.7 ± 5.1 pucuk setiap tunggul diikuti dengan kedominanan sebanyak 3.7 ± 0.7 pucuk setiap tunggul selepas pertumbuhan selama 42 bulan. Pucuk dominan mencapai purata ketinggian 470 ± 133 cm dan garis pusat 3.4 ±1.5 cm pada 50 cm dari aras tanah. Persamaan regresi linear [$y = a + b(nd^2h)$, ukuran ketinggian dan garis pusat pucuk yang paling dominan dan pengiraan bilangan pucuk kopis setiap pokok] didapati peramal terbaik bagi biojisim disebabkan oleh pekali korelasi yang tinggi dan keertian pekali regresi ($p < 0.001$, $p < 0.01$). Persamaan menggunakan ketinggian atau garis pusat sahaja mempunyai fungsi korelasi yang lemah. Pada umur 3.5 tahun, tanaman kopis menghasilkan sejumlah 82.7 t $ha^{-1}$ biojisim hijau dengan hampir 90% peruntukan biojisim kepada batang (43.2 t $ha^{-1}$) dan dahan kayu (31.2 t $ha^{-1}$). Daun (8.32 t $ha^{-1}$) menyumbangkan secara marginal. Jisim keringan ketuhar bagi kayu batang (23.2 t $ha^{-1}$) adalah maksimum diikuti masing-masing oleh kayu dahan (18.7 t $ha^{-1}$) dan daun (2.15 t $ha^{-1}$). Mutu bahan api bagi tumbuhan kopis dinilai berdasarkan indeks nilai bahan api kayu (607 ± 65.7 hingga 1518 ± 81.8) dan nisbah biojisim-habuk (29 hingga 37) berbeza dengan banyaknya bergantung kepada ketebalan pucuk. Kajian menunjukkan potensi sistem kopis dalam *P. juliflora* untuk mencapai kayu bahan api yang bermutu di bawah pusingan tebangan yang pendek (< 4 tahun) di atas tapak tanah substandard.

## Introduction

In India saline and alkaline soils occupy nearly seven million hectares of land and have been regarded as unfit for traditional agriculture on account of the high concentration of soluble salts and exchangeable sodium (Khoshoo 1987). Recognising the seriousness of the energy crises, these tracts can be usefully exploited for raising short rotation fuelwood plantations. This will help in meeting the ever-increasing demand for wood-fuel, fodder and timber, saving of the valuable forest resources and ameliorating the fertility status of fragile soils for sustained development.

*Prosopis juliflora* is well known for its hardy nature, multiple uses and N-fixing ability. It grows profusely and forms a dominant woody element over large areas of the world particularly on infertile soils, deserts and semi-arid communities. It provides an excellent opportunity to develop an enterprise that markets wood as fuel. Quantitative estimation of above-ground biomass consisting of stem wood, branch wood and leaves is important to measure stand yield without harvesting whole tree. Height and diameter of a tree are the major yield components that determine the amount of harvestable wood; accordingly, it is possible to derive functional relationship between growth parameters and biomass that can be used to predict above-ground biomass with considerable accuracy (Vasudevan *et al.* 1986, Chaturvedi & Behl 1996). However, a recent search of literature revealed that there is a striking lack of published information on biomass prediction of coppice plants (multi-stemmed plants) of *Prosopis juliflora*. The present study aimed to investigate growth, biomass yield and fuel quality of coppice plants of *P. juliflora* on a highly alkaline soil site.

## Materials and methods

### *Experimental site and trial*

The soil of the experimental area at Banthra, Lucknow (India), is characterised by high pH (8.6 to 10.5), high bulk density (1.55 to 1.70 g $cm^{-3}$) and poor soil-water-air relationship. Presence of thick salt concretions as granules at 45 to 100 cm depth and anaerobic stress created as a result of water logging restrict normal plant growth. A 5-y-old trial of *P. juliflora*, raised for fuelwood production, was coppiced 5 cm above the ground level. The plants were spaced at a square spacing of 1 × 1 m corresponding to a density of 10 000 plants $ha^{-1}$. In order to avoid boundary effect, two outermost rows were excluded from observations. Data were taken from for a minimum of sixteen plants from each of the six replications. Individual coppice plants were investigated for emergence of sprouts and number of surviving coppice shoots (both total and dominant shoots) and their height and diameter were measured at periodic intervals of 12, 24, 36 and 42 months over a period of 42 months (3.5 y).

### *Sampling*

To estimate the above-ground biomass of 3.5-y-old coppice plants, destructive sampling of 50 stems (coppice shoots) with diameter of 1.0 to 6.8 cm was carried out with a chainsaw. In all a total of 18 plants were felled. The total fresh weight of each component (stem, branches and leaves) was determined in the field. A small portion was dried at 70 °C to constant weight and weighed immediately after removal from the oven. Linear regression equations were developed for green and oven-dry weights of each component separately.

Wood samples were collected to study fuel quality of coppice shoots varying in diameter from 2 to 6 cm. Wood density, heat of combustion, moisture content and ash content were determined to determine biomass–ash ratio and fuel value index (FVI) as suggested by Goel and Behl (1996).

## Results and discussion

### *Growth*

Growth data of coppice plants of *P. juliflora* recorded periodically for 42 months are presented in Table 1. During the first year, coppice plants showed emergence of 11.6 ± 5.1 sprouts per stump (range 2–19 sprouts per stump). The number of sprouts per stump was positively correlated (r=0.61) with the thickness of the stem prior to felling. Coppice plants appeared like a bush with multi-stems. Sprout number decreased to 6.2 ± 1.6 per stump followed by dominance of only 3.7 ± 0.7 shoots per stump at the age of 42 months. This reduction in number of coppice shoots with increasing age was due to drying of poor shoots which could not grow properly for want of solar radiation (Verma & Misra 1987).

**Table 1.** Growth of coppice plants of *Prosopis juliflora* (mean ± s.d.)

| Age (months) | Emergence of sprouts (number) | | Dominant shoot growth (cm) | |
|---|---|---|---|---|
| | Total sprouts | Dominant sprouts | Shoot length | Shoot diameter |
| 12 | 11.6 ± 5.06 | 9.85 ± 1.51 | 94.96 ± 43.70 | 0.86 ± 0.35 |
| 24 | 8.93 ± 1.98 | 4.31 ± 1.64 | 242.42 ± 54.03 | 1.96 ± 0.73 |
| 36 | 6.92 ± 1.51 | 3.96 ± 0.70 | 386.71 ± 114.75 | 2.76 ± 0.94 |
| 42 | 6.23 ± 1.62 | 3.67 ± 0.74 | 470.00 ± 133.00 | 3.39 ± 1.50 |

Dominant shoots, 42 months old, attained an average height of 470 cm (range 105 to 680 cm) and a diameter of 3.4 cm (range 0.39 to 8.08 cm) at 50 cm above the ground (Table 1). The diameter was 2.98 cm (range 0.34 to 7.1 cm) at 130 cm above the ground level. The early and fast growth rate of coppice shoots was because of well-established parental root system. Ferm and Kauppi (1990) reported that faster growth rate of coppice shoot was mainly because of their better photosynthetic potential and good root system. It was interesting to note that faster growing coppice stems were indicative of the larger pre-harvested stumps and showed a positive correlation ($r=0.59$). Truman and Francombe (1991) also observed a similar relation between size of the dominant shoot and diameter of the stump in leleshwa and reported that this may be because of the inherent nature of larger stumps to produce faster growing coppice shoots.

### *Biomass relationships*

To predict the above-ground biomass of standing cover, linear regression equations were developed defining relationship between growth parameters (independent variable) and biomass (dependent variable) as given below:

$y$ = $a + b$ (x); where,
$y$ = biomass yield in kg (dependent variable)
$x$ = growth parameters (independent variable)
$a, b$ = regression constants

The relationships were observed for stemwood, stemwood + branchwood, and total biomass yield. Four sets of equations were developed to predict biomass of coppice plants, one set using height ($h$) alone, one using diameter ($d$) alone, and the third set both height and diameter ($d^2h$) as an independent variable. The fourth set of equation included the total number of emerging shoots per stump ($n$) along with the height and diameter measurements of the most dominant shoot ($nd^2h$).

Regression analysis based on $nd^2h$ of the plant (dominant shoot diameter at 50 cm or 130 cm from the ground level) was found to be the best predictor of green and dry weights of stem, branch and leaves. The output of resulting equations and their regression parameters are presented in Table 2. A strong positive correlation ($r^2= 0.97, 0.98$) exist between shoot $nd^2h$ and stem biomass yield. The regression coefficients and correlation coefficients were highly significant ($p<0.01$, $p<0.001$) showing a definite increase in biomass yield with corresponding increase in $nd^2h$ of the plant. In all equations when branch and/or leaf biomass were included with stem biomass, values of $r^2$ and significance of regression coefficient and correlation coefficient became diluted and equation constants $a$ and $b$ increased. Foliage weights can be estimated with relatively low precision but this component formed only a small fraction of the total above-ground biomass. These equations are useful for quick determination of standing biomass of multi-stemmed coppice plants of *P. juliflora.* Chaturvedi *et al.* (1991) used similar equation (Biomass = 0.607+0.852 $nd^2h$) for reasonably accurate prediction of biomass yield of multi-branched species like *Acacia farnesiana.*

None of the linear equations involving height or diameter alone as an independent variable was appropriate for biomass prediction of coppice plants because of relatively low values of correlation coefficients and irregularly scattered points between dependent and independent variables. Better prediction is provided by using a combination of these parameters ($d^2h$, $nd^2h$) (Figure 1). Biomass equations based on $d^2h$ and $nd^2h$ of the shoot (diameter at 50 cm from the ground) showed significant relationships ($r^2$=0.89 and 0.92 respectively) with above-ground biomass (Tables 3 and 2 respectively). As coppice plants are multi-stemmed, it is laborious and time consuming to take growth measurements of each shoot as required for use of this equation. Singh *et al.* (1990) reported height to be a redundant factor while basal radius indicated an almost linear relationship with weight in *Adhatoda vasica.* Similar to our study, Chaturvedi and Behl (1996) observed the most significant relationship of $d^2h$ with biomass in simple linear regression equations of several tree species. Madgwick *et al.* (1991) obtained reliable estimates of stem weights in *Eucalyptus* species from basal area and mean stand height with significant relationship. Felker *et al.* (1983) developed regression equations relating stem diameter and fresh biomass or dry matter contents for 1-y-old and 3-y-old *Prosopis* species.

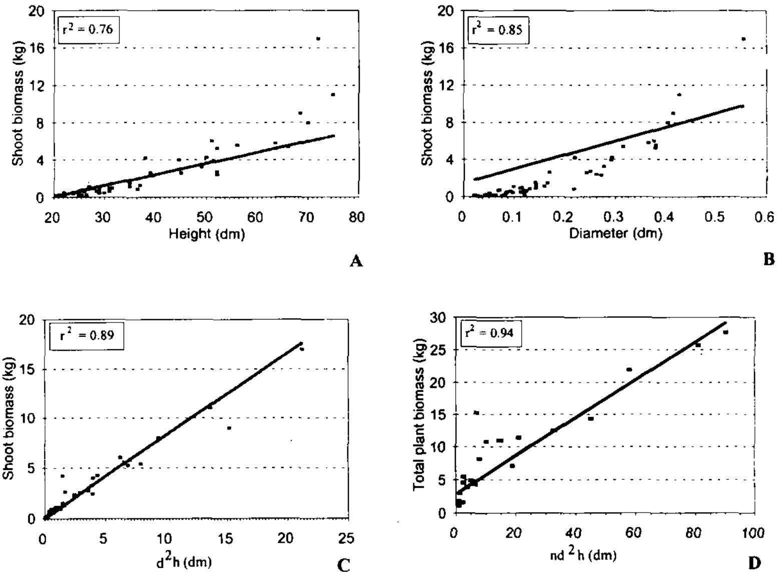

**Figure 1.** Relationships between coppice shoot biomass and growth parameters (A) height, (B) diameter, (C) $d^2h$; and (D) between total plant biomass and $nd^2h$

**Table 2.** Regression equations relating $nd^2h$ (total number of coppice shoots emerging per stump x square of dominant shoot diameter x height) to green and oven-dry biomass yield of 3.5-y-old coppice plants of *Prosopis juliflora*

| Biomass component | *a* | *b* | sb | $r^2$ | sr | n |
|---|---|---|---|---|---|---|
| | i) $y = a + b(nd^2h)$ diameter 50 cm from the ground level | | | | | |
| Green weight | | | | | | |
| Stem | 0.677 | 0.148 | 0.007 | 0.97 | 0.007 | 18 |
| Stem+branch | 1.860 | 0.23 | 0.016 | 0.93 | 0.017 | 18 |
| Stem+branch+leaf | 2.179 | 0.252 | 0.018 | 0.92 | 0.019 | 18 |
| Dry weight | | | | | | |
| Stem | 0.320 | 0.082 | 0.003 | 0.97 | 0.007 | 18 |
| Stem+branch | 0.839 | 0.137 | 0.007 | 0.95 | 0.012 | 18 |
| Stem+branch+leaf | 0.939 | 0.142 | 0.008 | 0.94 | 0.014 | 18 |
| | i) $y = a + b(nd^2h)$ diameter 130 cm from the ground level | | | | | |
| Green weight | | | | | | |
| Stem | 1.085 | 0.169 | 0.006 | 0.98 | 0.005 | 18 |
| Stem+branch | 2.475 | 0.264 | 0.015 | 0.95 | 0.013 | 18 |
| Stem+branch+leaf | 2.852 | 0.289 | 0.018 | 0.94 | 0.017 | 18 |
| Dry weight | | | | | | |
| Stem | 0.544 | 0.093 | 0.003 | 0.98 | 0.005 | 18 |
| Stem+branch | 1.212 | 0.156 | 0.007 | 0.97 | 0.007 | 18 |
| Stem+branch+leaf | 1.320 | 0.163 | 0.008 | 0.96 | 0.009 | 18 |

*a* & *b* = regression coefficients
sb = error of regression coefficient '*b*'
$r^2$ = correlation coefficient
sr = error of correlation coefficients '*r*'
n = number of observations

The regressions were tested on plants that were not included in computation of the original equations. For example, the predicted biomass (28.5 kg) of a plant (length = 75 dm, diameters at 50 and 130 cm from ground = 0.48 and 0.47 dm respectively and total shoots per stump = 6) differed marginally from the total actual biomass (26.8 kg) when $nd^2h$ was used as independent variable in the equation. However, in the equation $y = a + b\ (d^2h)$, the estimated biomass of one shoot of the same plant was 11.5 kg as against the actual biomass of 11 kg (Table 4).

**Table 3.** Linear regression equations relating growth parameters (plant height, diameter and $d^2h$) to green biomass yield of coppice shoots of *Prosopis juliflora*

| Biomass component | $a$ | $b$ | sb | $r^2$ | sr | n |
|---|---|---|---|---|---|---|
| i) $y = a + b(h)$ | | | | | | |
| Stem | -1.360 | 0.066 | 0.005 | 0.81 | 0.027 | 50 |
| Stem+branch | -2.203 | 0.111 | 0.008 | 0.77 | 0.032 | 50 |
| Stem+branch+leaf | -2.330 | 0.119 | 0.010 | 0.76 | 0.034 | 50 |
| ii) $y = a + b$ (diameter at 50 cm from the ground level) | | | | | | |
| Stem | -0.810 | 8.25 | 0.440 | 0.87 | 0.018 | 50 |
| Stem+branch | -1.318 | 14.19 | 0.843 | 0.86 | 0.020 | 50 |
| Stem+branch+leaf | -1.390 | 15.14 | 0.911 | 0.85 | 0.210 | 50 |
| iii) $y = a + b$ (diameter at 130 cm from the ground level) | | | | | | |
| Stem | -0.450 | 8.187 | 0.401 | 0.89 | 0.015 | 50 |
| Stem+branch | -0.707 | 14.10 | 0.759 | 0.88 | 0.017 | 50 |
| Stem+branch+leaf | -0.740 | 15.04 | 0.825 | 0.87 | 0.018 | 50 |
| iv) $y = a + b$ ($d^2h$ diameter at 50 cm from the ground level) | | | | | | |
| Stem | 0.049 | 0.366 | 0.088 | 0.97 | 0.004 | 50 |
| Stem+branch | 0.182 | 0.614 | 0.028 | 0.90 | 0.014 | 50 |
| Stem+branch+leaf | 0.213 | 0.653 | 0.032 | 0.89 | 0.015 | 50 |
| v) $y = a + b$ ($d^2h$ diameter at 130 cm from the ground level) | | | | | | |
| Stem | 0.166 | 0.411 | 0.013 | 0.95 | 0.007 | 50 |
| Stem+branch | 0.368 | 0.696 | 0.030 | 0.89 | 0.015 | 50 |
| Stem+branch+leaf | 0.409 | 0.739 | 0.039 | 0.88 | 0.017 | 50 |

$a$ & $b$ = regression coefficients
sb = error of regression coefficient '$b$'
$r^2$ = correlation coefficient
sr = error of correlation coefficient '$r$'
n = number of observations

### *Biomass estimations*

Regression equations based on $nd^2h$ were used for assessing green and oven-dry biomass of coppice plants of *P. juliflora*. The 3.5-y-old coppice stand produced a total of 82.77 t ha$^{-1}$ green biomass with nearly 90 % biomass allocation to stem (43.27 t ha$^{-1}$) and branch wood (31.17 t ha$^{-1}$). Leaves (8.33 t ha$^{-1}$) contributed marginally. Accordingly, dry weight of plants calculated on the basis of oven-dry biomass equations showed maximum quantity of stem wood (23.2 t ha$^{-1}$) followed by branch wood (18.7 t ha$^{-1}$) and leaf biomass (2.15 t ha$^{-1}$).

**Table 4.** Comparison between actual coppice biomass yield and estimated yield from regressions

| S. No. | Growth parameters (dm) | | | Actual yield (ST+BR+LF) | Estimated yield from regressions (kg) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Height | Diameter | | | Equation I | Equation II | Equation III | Equation IV | Equation V |
| | | at 50 cm | at 130 cm | | | | | | |
| 1 | 75.0 | 0.481 | 0.472 | 11.0 | 6.59 | 5.89 | 6.35 | 11.54 | 12.75 |
| 2 | 63.5 | 0.376 | 0.365 | 5.8 | 5.22 | 4.30 | 4.74 | 6.07 | 6.66 |
| 3 | 55.0 | 0.302 | 0.283 | 2.0 | 4.21 | 3.18 | 3.51 | 3.48 | 3.66 |
| 4 | 57.0 | 0.270 | 0.246 | 2.2 | 4.45 | 2.69 | 2.95 | 2.92 | 2.95 |
| 5 | 78.0 | 0.250 | 0.244 | 3.0 | 6.95 | 2.39 | 2.92 | 3.39 | 3.80 |
| 6 | 67.0 | 0.235 | 0.222 | 2.8 | 5.64 | 2.16 | 2.59 | 2.62 | 2.84 |
| 7 | 72.0 | 0.612 | 0.554 | 17.0 | 6.23 | 7.87 | 7.59 | 17.82 | 16.74 |
| 8 | 68.5 | 0.531 | 0.414 | 9.0 | 5.82 | 6.64 | 5.48 | 12.82 | 9.08 |
| 9 | 48.4 | 0.285 | 0.258 | 2.5 | 3.42 | 2.92 | 3.14 | 2.78 | 2.79 |
| 10 | 70.0 | 0.412 | 0.404 | 8.0 | 6.00 | 4.84 | 5.33 | 7.97 | 8.85 |
| 11 | 66.0 | 0.391 | 0.351 | 5.4 | 5.52 | 4.52 | 3.99 | 6.80 | 5.24 |

Equation I : $y = a+b\,(h)$
Equation II : $y = a+b\,(d)$, diameter at 50 cm
Equation III: $y = a+b\,(d)$, diameter at 130 cm
Equation IV: $y = a+b\,(d^2h)$, diameter at 50 cm
Equation V : $y = a+b\,(d^2h)$, diameter at 130 cm

Coppice plants produced maximum stemwood that is the most valuable part of the biomass as it provides higher market prices than branchwood when fuelwood farming is carried out as a business. The leaf portion is of the lowest market value but it has a significant contribution in soil amelioration of sodic sites through litter fall and its decomposition.

### *Fuel quality*

Analysis of fuel quality of coppice shoots revealed marked differences in fuel value index (607.8 ± 65.7 to 1518 ± 81.8) (Figure 2) and biomass-ash ratio (29 to 37.0). These differences were associated with variations in wood density (0.52 ± 0.02 to 0.74 ± 0.04 g ml$^{-1}$), moisture (40.6 ± 1.32 to 54.8 ± 2.59 %) and ash content (2.7± 0.12 to 3.4 ± 0.16 %) depending on shoot thickness (2 to 6 cm thick). Heat of combustion varied marginally (21.6 to 22.7 kJ g$^{-1}$). The value of FVI was highly correlated with density ($r^2$= 0.96) followed by ash ($r^2$=0.83) and moisture content ($r^2$=80). It had poor correlation with calorific value ($r^2$=0.59). Goel and Behl (1995, 1996) observed differences in FVI of several tree species and reported density as the most important and crucial factor in evaluating the fuelwood quality of a plant.

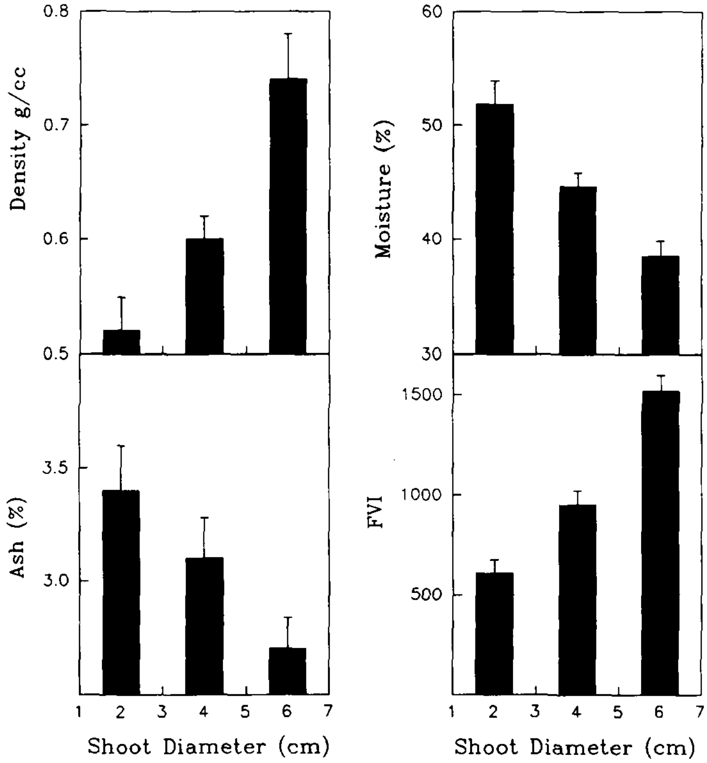

**Figure 2.** Fuel quality parameters, density, ash, moisture content and fuel value index, of *P. juliflora* coppice shoots of varying diameter classes

## Conclusion

The coppice system in *Prosopis juliflora* has great potential for short rotation (< 4 y) multiple fuelwood harvests on sub-standard soil sites. This system can provide high biomass yield, desirable thickness of wood and acceptable quality fuel for domestic and other uses like gasifiers if proper silvicultural and management practices are applied.

It is important to assess productivity in the subsequent harvests to optimise biomass potential. A study of alternative silviculture practices such as thinning and pruning, and nutrient cycling will be useful to develop appropriate practices for the re-forestation of and wood fuel production on degraded soil sites.

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