loping juveniles[8] were noticed on all infected cysts and eggs.

Thus, *C. herbarum* offers a great potential to pigeonpea growers in the management of pigeonpea cyst nematode. Further studies on the development of a formulation using this biocontrol agent for delivery into the soil are under progress in our laboratory.


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# Oxygen ($^{18}O$) isotopic enrichment in the leaves as a potential surrogate for transpiration and stomatal conductance

Water is perhaps the most important constraint that limits productivity under tropical conditions. Among a number of adaptive strategies developed by plants, water use efficiency, (WUE, ratio of the amount of biomass produced over a period of time to the total water transpired during the same period) is most noteworthy.

Increase in WUE is normally achieved through a reduction in transpiration rate ($T$). Due to the direct relationship between $T$ and biomass production, selection for high WUE often accompanied a reduction in total biomass[1]. This interdependency seems to be the major reason for the lack of success in breeding for increased WUE[2].

In genotypes where the interdependency between $T$ and WUE is weak, selection for high WUE would not accompany a reduction in biomass. Therefore, it is essential to measure the variability in both $T$ and WUE. While the genetic variability in WUE can be determined by the carbon isotope discrimination technique ($\Delta^{13}C$), no such measure of $T$ integrated over time average is available. This necessitates the development of a suitable technique to measure $T$ on a time-integrated basis.

Stable oxygen isotopes have generated considerable interest in plant carbon and water relations in recent years. Water vapour molecules containing the lighter isotope of oxygen ($^{16}O$) diffuse relatively faster than do molecules with the heavier isotope ($^{18}O$), so that during evaporation, water gets enriched with the heavy isotope molecules[3]. Further, the isotopic enrichment occurs during evaporation also, because the vapour pressures of $^{18}O$ water is lower compared to that of the $^{16}O$ water[3,4].

In this paper, we demonstrate that this feature can be utilized to measure the rate of transpiration and stomatal conductance ($g_s$) in plants.

Seven genotypes of cowpea significantly differing in $T$ (based on our previous experiments) were selected and raised in battery containers. The mean transpiration rate was determined by gravimetric approach standardized at our center[5]. Stomatal conductance ($g_s$) was measured by gas exchange methods on the fully expanded top leaves of these genotypes.

Leaf water from fully expanded leaves was collected by freezing (liquid nitrogen) and thawing (boiling water bath) 50 leaf punches (1 $cm^2$) in sealed plastic tubes. The tubes were purged with dinitrogen to remove the air inside and all extraction work was carried out in this condition only. Later leaf water was drawn after centrifuging the tubes using a syringe. $^{18}O$ composition of the leaf water was determined (in 500 µl of water) by direct equilibration with $CO_2$ in specific vacutainer tubes[6] using an isotope ratio mass spectrometer (IRMS).

The stomatal conductance showed a strong positive correlation with $^{18}O$ composition of leaf water suggesting that

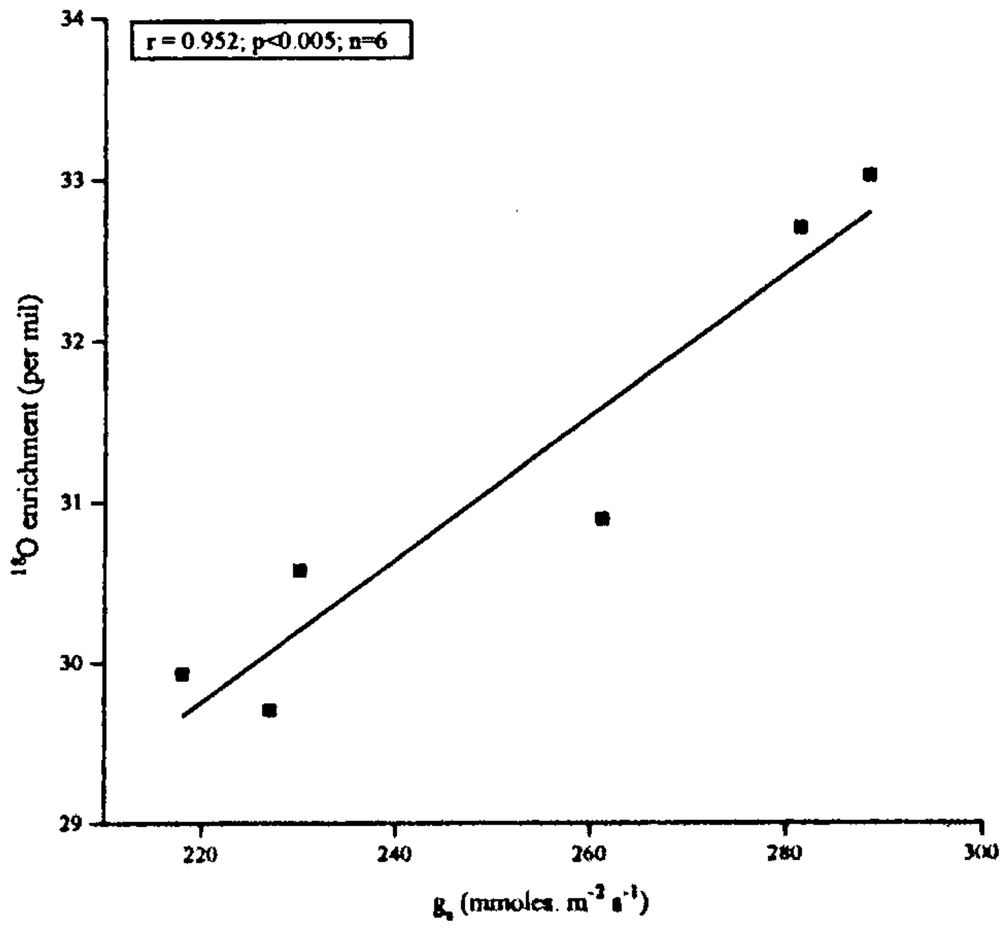


**Figure 1.** Relationship between stomatal conductance ($g_s$) and $^{18}O$ enrichment in leaf water in six contrasting cowpea genotypes. The $g_s$ was determined using a portable photosynthesis system on the top of a fully expanded leaf (light intensity > 1500 µmoles $m^{-2}$ $s^{-1}$). Each value is an average of at least three replicates.

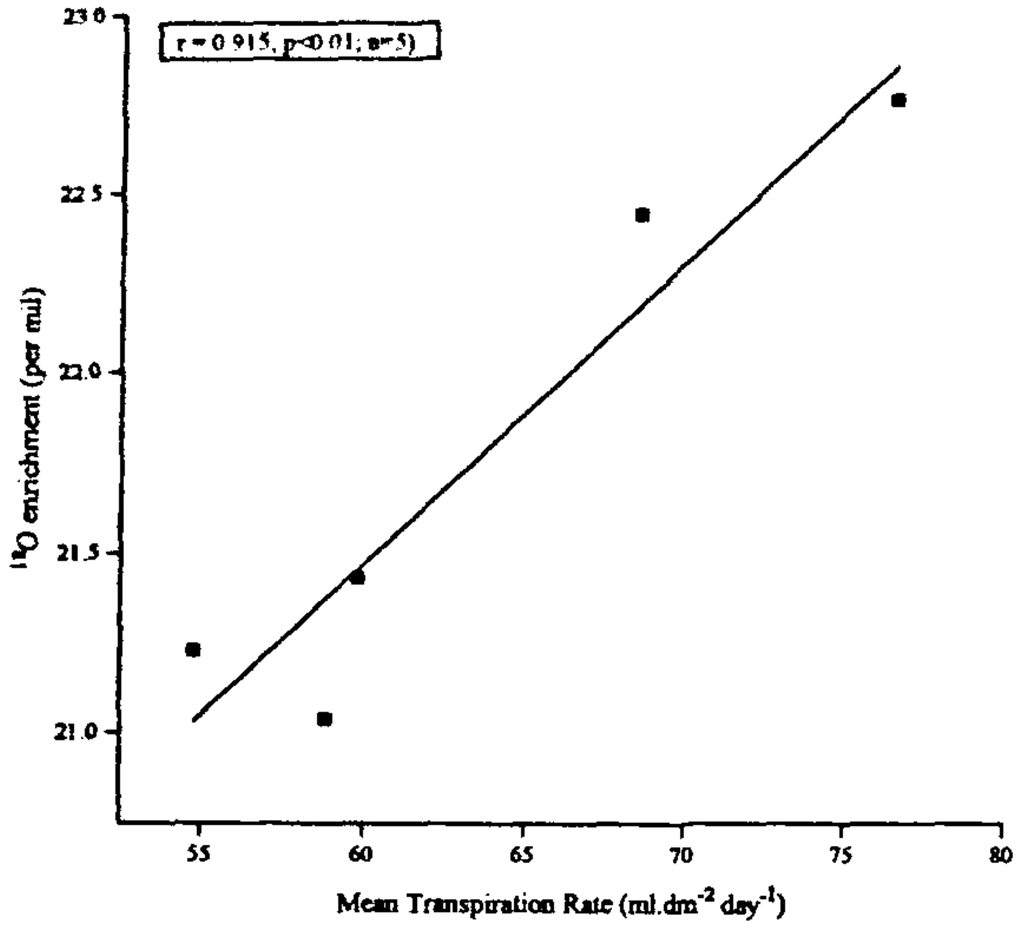


**Figure 2.** Relationship between $^{18}O$ enrichment in leaf biomass and mean transpiration rate in contrasting cowpea genotypes. The daily water loss over a period of 25 days (30–55 DAS) was summated to arrive at the total water loss. The MTR was computed from the ratio of the total water transpired to the total functional leaf area retained during the experimental period. Each value is an average of at least three replicates.

oxygen isotopic enrichment occurs in leaf water due to $g_s$ (Figure 1). The mean transpiration rate (MTR) derived based on gravimetry on the day of leaf water extraction also recorded a similar linear relationship with leaf water $^{18}O$ ($r = 0.83$; $p < 0.005$; $n = 7$). The enriched $^{18}O$ finds its path into the cellulose through a metabolism leading to its synthesis[7]. Therefore, the $^{18}O$ composition in leaf biomass can be considered as a reflection of the $^{18}O$ enrichment that occurred over an extended period of time.

Dried leaf powder of the cowpea genotypes was analysed for the $^{18}O$ composition by on-line pyrolysis at the PDZ-Europa, UK, using an IRMS (*Geo 20–20*). The $^{18}O$ composition in biomass also showed a significant positive relationship with mean transpiration rate (Figure 2). These results clearly suggest that, the variations in the $^{18}O$ enrichment that occur in leaf water are due to differences in $T$ and $^{18}O$ in leaf biomass can be effectively used as a powerful surrogate for the time integrated estimation of transpiration rate and $g_s$. Although an increase in $^{18}O$ in leaf water as influenced by environmental variables like vapour pressure difference (VPD) has been reported[8], our results suggest that despite such confounding factors, this technique can be employed for the determination of $T$ and $g_s$. Further, we show here, for the first time, that the mean transpiration rate is related to the $^{18}O$ enrichment in leaf biomass and the genetic variability in $T$ and $g_s$ can be quantified by the $^{18}O$ enrichment technique. Besides this, the observed differences in $^{18}O$ enrichment can also be used to ascertain whether stomatal factors or the mesophyll capacity brings about the genetic variability in WUE[2]. This could significantly help efforts to improve WUE.

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ACKNOWLEDGEMENTS. We acknowledge Dr Anura V. Kurpad, Head, Nutrition Research Center, St. John Medical College, Bangalore and Dr Steeve Brookes, Sales Manager, PDZ-Europa, UK, for helping in analysing the samples for leaf water and biomass $^{18}O$ composition respectively.

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# The iron pillar at Kodachadri in Karnataka

The historical iron pillars at Mehrauli, Delhi, and at Dhar, in Madhya Pradesh, have attracted the attention of scientists for over a century and have been the subject matter of many publications (e.g.)[1–4]. However, a third iron pillar located in *Ādi-Mookāmbikā* temple at Kodachadri village in a remote forest area of the Western Ghats in Karnataka has not received much scientific attention so far, partly because the concerned village is difficult to reach and partly because the pillar itself is not as massive and imposing as the Delhi and Dhar monuments. Even the Dhar pillar too has not been subjected to systematic scientific and archaeo-historical studies like the Delhi pillar. In fact, two books have already appeared[5,6] on this pillar, dated to mid-Gupta period (~ 375 A.D.) and located in the vicinity of the still more famous Kutub Minar.

Propelled by scientific curiosity as well as deep interest in India's glorious metallurgical heritage, the present author embarked on the adventurous journey to Kodachadri twice during the last eighteen