It is said that money doesn’t grow on trees — but gold and other precious metals can actually accumulate in their leaves.

Certain plants are known to have a natural capacity to take up and concentrate metals such as nickel, cadmium and zinc in their leaves. Currently, the main interest in metal accumulating plants, called hyper-accumulators, lies in the field of phytoremediation where plants are used to ‘clean up’ metal pollutants from soil. Hyper-accumulating plants can accumulate metal to a concentration that is 100 times more than ‘normal’ plants growing in the same environment.

The practice of finding metals, known as phyto-mining, uses plants to extract particles of metal from soil. However, application of phyto-mining to extract gold from soil is a comparatively newer approach. This is mainly because gold is extremely insoluble under natural conditions which limits its bioavailability and thus reduces its potential for phyto-extraction.

So, metal solubilising compounds are applied to the soil to power hyper-accumulation. This technique is known as induced hyper-accumulation and provides the basis for the development of phyto-mining. It is a novel extraction technique to exploit precious metal resources from soil.

Phyto-mining vs Conventional Mining

Conventional mining is typically accomplished using the ores that have a high concentration of the target metal (> cut-off grade) and calls for huge principal investment. To be economically feasible, such an operation necessitates ore bodies with adequate ore deposits.

On the contrary, phyto-mining encompasses the use of hyper-accumulating plants to extract precious metals from soil. Some metals like nickel, cadmium and manganese are bio-available in the soil solution for plant uptake. Such metals can be naturally extracted from hyper-accumulating plants growing over such deposits.

Phyto-mining is less invasive and entails reduced energy compared to the resource-intensive traditional mining techniques which require considerable site remediation at the end-of-life of the mine. Its negative influence on the environment is negligible because the plants have stabilizing action on soil over the erosion caused by open-cast mining operation.

The generation of bio-ore by phyto-mining uses solar energy. These “bio-ores” are nearly sulphur free and their smelting involves less energy than sulphide ores. In addition, a bio-ore usually has much higher metal content than that of a conventional ore and requires less storage space.

However, some metals are insoluble and consequently not bio-available to plants. Gold, lead, zinc and uranium are few of them. In such cases, the phenomenon of phyto-mining may be induced in some high biomass plant species by addition of chemicals to solubilize such metals and make them available for plant uptake.
For metal extraction the plant is harvested in conventional approach by cutting the plant roots, and dried. This is followed by haymaking and is then incinerated to ash with or without energy recovery. This yields the ‘bio-ore’ with high residual metal concentration.

History of Phyto-mining
The first phyto-mining experiments were carried out in California in 1983 using the nickel hyper-accumulator *Streptanthus polygaloides* with a yield of 100 kg/ha of sulphur-free nickel. Lungwitz in 1900 first suggested the analysis of plant tissue for gold to locate the gold deposits. This was followed by numerous attempts all over the globe to extract gold via phyto-mining but the concentration of accumulated gold was very low.

Finally, the first report of induced phyto-mining for extracting gold was reported 15 years ago when an international group of scientists from Italy, New Zealand and France used Indian mustard (*Brassica juncea*) for this purpose. They reported gold accumulation up to a concentration of 1 mg/kg in contrast to 0.1 mg/kg in normal plants.

Almost at the same time another group of scientists from United States reported extraction of uranium from soil using induced phyto-mining. Later studies demonstrated the application of other crop plants viz. carrot (*Daucus carota*), red beet (*Beta vulgaris*), onion (*Allium cepa*), and two cultivars of radish (*Raphanus sativus*) for successful phyto-mining of gold.

Gold Extraction – Green Approach
Gold is extensively distributed all over the earth’s crust at a very low level (0.005 mg/kg). The paucity of gold and its value, due to mankind’s enthrallment, have made gold one of the most significant metals in our daily life.

Worldwide, there are large tonnages of gold deposits in natural mineralized soil or in-mine waste, and are wasted if not explored. Phyto-mining not only provides a potential route of extracting precious metals from these areas, it also additionally increases levels of soil carbon, nutrients and biological activity, thereby increasing the success rate of subsequent native planting strategies.

It has been shown that gold uptake can be prompted using lixiviates such as sodium cyanide (NaCN), thiocyanate, thiosulphates, etc. These compounds chelate Au (0) and convert it into Au (I) or Au (III), which are easily bioavailable. A single treatment induces the plant to accumulate approximately 20% of the total amount of gold present in the soil.

Phyto-mining processes involve planting a selected hyper-accumulator plant species over low grade ore or mineralized soil or metalliferous mine spoil or mill tailings. These plant species have high biomass yield and are fast growing and can grow in high mineral-containing soil. Increasing the above-ground biomass of the plant species can enhance the efficiency of metal accumulation ultimately resulting in an increased metal concentration in shoots. When the plant matures and attains maximum biomass, appropriate solubilizing agent called ‘chelates’ are applied in the soil.

The concentration of gold in the soil and choice of solubilizing agent to be applied in the auriferous soil is strongly dictated by the geochemistry of the ore substrate or tailings. For example, low-pH oxidized sulphide tailings are known to have a high level of extractable gold which is generally made soluble by thiocyanate while high pH unoxidized tailings have relatively low percentage of extractable gold which is solubilized by thiosulphate and cyanide. This is due to the relevant gold complexes being stable under different geochemical conditions.

For metal extraction the plant is harvested in conventional approach by cutting the plant roots, and dried. This is followed by haymaking and is then incinerated to ash with or without energy recovery. This yields the ‘bio-ore’ with high residual metal concentration. This is followed by roasting, sintering or conventional smelting to extract gold from the ‘bio-ore’. Further gold from ash ‘bio-ore’ can be recovered via high temperature pyrolysis or combustion followed by smelting the ash or acid digestion of the plant matter followed by electro-winning or solvent extraction.

Together, it can be said that phyto-mining of gold is a ‘green’ approach in contrast to the conventional practice of mining which is environmentally sensitive and energy intensive. It provides a sustainable alternative to the orthodox mining methods. Market prices of gold are increasing incessantly and if high gold content and high plant biomass are achieved, phyto-mining for gold can be lucrative.

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