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ROLE OF VARIOUS GROWING SUBSTRATES ON THE YIELD AND QUALITY OF GREENHOUSE CROPS

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Abstract

In the present era, the land is squeezing by increasing the population all over the world. Pakistan is also a hit country having similar problem in the area of agriculture. The need of shelter for 160 million people of Pakistan has changed the societal trend from rural to urbanization and reduced the cultivable land to great extent. All such major factors may bring disastrous effect in future, thus affecting the socio-economic condition of our country. Under such scenario, horticulture has contributed considerably to cope with the food shortage coupled with the agronomic crops. However due to shortage of land, and more importantly, the existence of problematic land the progressive growers have been compelled to alter the routine of crop production under conventional methods by adopting the new but innovative techniques of crop production. The introduction of varieties of growing media in the form of organic and inorganic substrates used for the production of horticultural crops under cover has gained momentum particularly during the last decade in view of high yield rather quality for greenhouse crop. The crop cultivation through hydroponics offers a lucrative opportunity to consider several kinds of growing media in addition to pure water culture. Some peculiar examples of growing substrates are perlite, rockwool, coconut fiber, peat, vermiculite, gravels, sand, etc. With the passage of time, new substrates are being introduced in the markets in terms of paramount factors, mainly including availability, cost effectiveness, growth impact, yield performance etc. Pakistan is blessed with a variety of natural sources including rich soils and diverse climate. Sand can be given as a productive example. In wheat growing areas farmers can benefit from residues of the crops ion the form of straw bales. All such substrates can be used as efficient tools for enhancing production in the greenhouses. This manuscript has highlighted the role of some growing substrates on the performance of seedlings and consequent upon the yield and quality of important horticultural crops. The outcome of this discussion will help in improving the growing crop pattern in our country.

INTRODUCTION

It is quite imperative to understand the physiological circumstances within which a root and a plant can function in a best way. The possible way could be coupled with the parameters measured in the plants that are grown on the chosen growing media. With the increasing output demands of protected cultivated plants, the subsequent pressure on the plant root system has also been increased (Butt, 2002). A growing medium is an inevitable need for the growth and development of a plant. The suitable selection of root medium is the first cultural consideration for a greenhouse crop. The different kind of growing media are used for better horticultural crop yields, depending on their availability, financial face value and practical utility. Plants grown in containers are restricted to a limited volume of media consequently the demand made for water, air and essential nutrients are more as compared to those made by soil grown plants which have an unrestricted root-run and an infinitely greater volume of soil in which to grow (Bunt, 1976). Therefore, organic matter contents, carbon/nitrogen ratio, bulk density, least percentage of air, cation exchange capacity (CEC), level of pH and the presence of all nutrients are the peculiar characteristics of greenhouse growing media (Nelson, 1991). Advances in science and technology now allow humans to provide the soil needs artificially and to successfully grow plants without soil. The salient advantages of soil less substrate can be taken down as follow (Butt, 2001):

- The provision of plant nutrients can be easily controlled.
- After crop harvesting, the cultivation of subsequent crop can be made without any gap.
- The provision of a bit higher temperature to the plants root zone, the earliness of crop can be materialized.
- It facilitates the economic aspect for irrigation and fertilization as compared to standard soil.
- Because of salts concentration under control, the water or solution leaching, in general, is not required.

SIGNIFICANCE AROUND THE WORLD

Holland seems to be a leading country to use the soil less culture technology by using various kinds of organic and inorganic substrates. Central Europe, Canada, Russia, USA, Japan, Korea, Jordan, Mexico and China have proved the worth for the production through soil less substrates. India, Iran and Thailand are newly emerging countries in this regard. The Middle East states are efficient beneficiaries. In the past during the last 50 years, only 10 hectares of land is recorded for soil less culture, while today more than 50,000 hectares is described for crop production through different substrates (Table 1) (Butt, 2007c).

Table 1: Examples of some horticultural crops commercially produced by using different soil less substrates in different parts of the world

Vegetables	Cherry tomato, egg plant, green bean, beet, winged bean, capsicum, bell pepper, cabbage, cauliflower, cucumbers, melons, radish, potato, head lettuce, fancy lettuce, endives, mustard, kale, beet greens, swisschard, spinach, green onions, carrot
Condiments	Parsley, mint, oregano, sweet basil
Fruit crops	Strawberry, banana
Flower/ornamentals	Anthurium, marigold, coleus, roses, carnations, mums, orchids, chrysanthemums
Medicinal crops	Aloevera, thyme, marjoram, parsley, sage, spearmint and savory
Potted flowers	geraniums, azalea, poinsettia, tulip

The dynamic era of substrate culture, probably, started in 1973, when the Danish Rock wool-Industry publicized their hydrophilic GRODAN-rock wool as a horticultural substrate. In the meantime the substrate culture, with its more than 60% of the glasshouse acreage in the Netherlands and 50% in Belgium and France, has become the most important growing technique. The replacement of soil with soil less culture has proven its ability to overcome the limiting factors of soil. The vegetable production on various types of soils was realized to be health hazard with respect to a number of aspects. Additionally, the environmental problems of that time created the incentive to relinquish soil culture and the inherent soil disinfection and, thus, soil less culture as an alternative was eventually available. As on top of that the yield was increased and the standardized substrate also allowed extensive automation (Benoit and Ceustermans, 1995).

SUBSTRATES USED IN CROP PRODUCTION

The growing substrates in soil less culture are broadly classified as organic and inorganic on the ground of the source from where the respective substrate is derived. Some growing substrates of economical potential, including sand, perlite, vermiculite, polystyrene, foam resins, peat of many types, barks of various origins, sawdust, pumice grape marc, straw bales and rock wool are to be found in a varieties of formulations used by the greenhouse growers, sold as commercial preparation, or recommended by research institutes (Butt, 2006). Clay pellets (clay aggregates) are also being used as a soil less media (Bunt, 1976, Nelson, 1991). It is evident that even textile waste can be used successfully, as a soil less growing media, in vertical bag culture (Figure 1) (Polyak, 1982). An interesting new product is the wood-fiber substrate "toresa", which may be used in place of expended clay and rock wool being assumed expensive substrates for soil less culture in many countries. It is made from wood chips, which are crushed and frayed mechanically under high pressure and then impregnated to improve its physical and chemical properties. The material is of uniform quality and can have appropriate nutrients added during manufacture. The material has so far been used successfully on many crops including cucumber and lettuce (Penningsfeld, 1993). Various parts of the coconut palm like the coconut husk, fiber from the husk, wood chips from the trunk and dried fronds, have been used as growing media to raise many vegetable crops successfully, using the closed system of hydroponics. Coconut fiber is especially regarded as an excellent medium if well shredded, and it can be used for at least 18 months. High yields of tomato and lettuce crops have been produced by the media of coconut palm (Reynolds, 1977 & 1979). Research work is being taken into account to find cheap and easily available alternative growing media in mixtures of tree fern fiber, coconut bark, pinus bark, sugar-cane fiber, ceramic pieces, spent-mushroom etc. with appropriate ratio of fertilizers (D'Andrea 1998 and Dematte.1998). The processed coal ash as a substrate has good prospects to use in the solid media culture for protected crop cultivation. Based on the test results, a culture system using Ash-ball (the commercial name of processed coal ash) as a substrate was developed. It was confirmed that tomato can be selectively produced either for higher yield or high quality by controlling the amount of nutrient solution supplied (Kuriyama et al., 1998). The inorganic substrate, polyurethane ether foam (PUR) which was commercialized from 1986, has now acquired a worldwide renown. In large scale growing, so far, positive results were experienced with tomato on 7-year-old PUR-mats (Benoit and Ceustermans, 1995). The evident reports have indicated the verifications of productive response of some substrates for the possibility of development of soil less cultures by using low cost substrates like grapes marc to point out the economic feasibility for greenhouse crop cultivation (Leoni et al., 1988). Experiment demonstrated the utilization of town sledge for lettuce production in the bags with perforated bottom. The sludge was harmless to the plants and the best growth was produced in sand: perlite: sludge substrate plus nutrient solution (Polyak, 1982).

Figure 1: Strawberry production through vertical bag culture

CHARACTERISTICS OF SOME GROWING SUBSTRATES

Peat

The start of peat culture (Figure 2) was found in 1948-49 (Sevgican, 1999b). In 1962, Penningsfeld initiated work on the use of pure peat as compost. Peat was introduced on a large scale and partly failed as a growing medium for tomato and cucumber in the late sixties. The emergence of modern plant feeding management automatically reintroduced peat and has made it a very frequently used substrate (Granqvist, 1981). In many countries of the world, it is widely used either by itself or in combination with other materials. The most important peat-producing countries in the West Europe are Germany, Finland, Sweden, Norway, Ireland and Scotland. Peat is formed by the partial decomposition of plants growing in areas having high rainfall, high humidity and low summer temperature. Under acid, water-logged conditions, and in the absence of nutrients, the micro-organisms, which would normally break down or decompose the plants, are excluded and only partial decomposition of the dead tissue occur. Differences between peat's are related to variations in local climate and in the species of the plants from which the peats are formed. The difference between the young, less humidified sphagnum peat and the sedge peat is believed to be their cellulose and lignin contents. An oven-dry peat sample contains over 75% by weight of Sphagnum moss fiber (Butt and Varis, 1998). The fiber should be stems and leaves of Sphagnum in which the fibers and cellular structure is recognizable. The samples must contain a minimum of 90% of organic matter on a dry weight basis. The typical properties of sphagnum peat are, bulk density 60-100 g l^{-1}, pore volume >96%, organic matter >98%, ash <2%, total nitrogen 0.5-2.5% by weight, cation exchange capacity 110-130 meq $100g^{-1}$ and pH (in water) 3.5-4.0 (Bunt, 1976). Peat culture has great potential of producing the high yield tomato and lettuce than grown in the soil. Different factors like type of peat, formulation of compost, water and liquid feeding all greatly influence on growth, yield and quality of fruit (The West of Scotland Agricultural College, 1972). Peat provides good water-holding capacity, drainage, aeration and biological and chemical stability and contains some nitrogen, a little over 1%, but is low in phosphorous and potassium. It is used alone or in combination with other materials such as vermiculite, perlite, polystyrene beads and other materials, in various mixtures with diverse physical characteristics. Peat has also a high cation-exchange capacity and maintains an adequate structure during cropping (Hartmann and Kester, 1972 and Papadopoulos, 1994).

Figure 2: Structures of some growing substrates, perlite (left), peat compost (centre) and grapes residues (right)

Perlite

Perlite is an alumino-silicate of volcanic origin (Figure 2). Two primary sources of perlite are the island of Milos in Greece and the island of Sardinia in Italy. It is widely used in America and many European countries including Turkey, where large natural deposits of this mineral are existed. Turkey possesses a perlite reservoir that amounts approximately 6 billion tonnes. When crushed and heated rapidly to 1000°C, it expands to form white, lightweight aggregates (weighing only 0.13 g cm^{-3}) with a close cellular structure. The average density of perlite is 128 kg m^{-3} (8 lb ft^{-3}) and available in a range of graded particle sizes. Typically the perlite particle size is over the range of 0-5 mm, predominantly 1.18-4.75 mm for the grade most commonly used. Because of its close cellular structure, water is retained three to four times more of its weight, but only on the surface of the aggregates or in the pore spaces between them (Butt and Varis, 1996). The actual water availability in perlite depends upon the grade of material used. But coarse perlite holds very little water; therefore, it is used for rooting the cuttings because it has less water but more air capacity. Perlite has virtually no cation exchange capacity and no buffering capacity, and is essentially neutral with a pH of 7.0-7.5. It is composed mostly of silicon dioxide (73%) and aluminium oxide (13%), and for practical purpose it can be considered devoid of plant nutrients. Plant grown in perlite are, therefore, largely dependent on liquid feeding (Bunt, 1976; Sevgican, 1999b). Perlite has been used extensively worldwide in soil and peat mixes for plant raising. Its use as a substrate for soil less production received particular attention in Scotland, Greece and other European countries (Butt and Varis, 2000). Extensive studies, reports and practical experience exist on the bag and gulley-reservoir methods pioneered in Scotland. In bag reservoir method, the key feature is that horizontal slits are cut about 3-4 cm up from the base of the bag. In this open system, any excessive nutrient solution applied collects to a depth of 3-4 cm in the bottom of the perlite in each bag. Aided by high capillary action of perlite, this reservoir ensures an uninterrupted water supply to the plants with just a few irrigations per day and without placing a high demand on the irrigation system for uniform water delivery (Papadopoulos, 1994).

Grapes marc

It is the grapes residue or the drags of pressed grapes after extracting the grapes juice (Figure 2). In literature, it is also named as vinasse. This valuable by-product is usually thrown away after alcohol distillation, adding environmental pollution noticeably.

Grapes marc contributes 20% of fresh fruit, out of which are included 15% fruit stalk and 85% skin and seeds (Pamir, 1984). The nutritive evaluation of grapes marc is more or less the same as that of straw bales. In an analysis, the fresh grapes marc contained 54% water, 6.6% raw protein, 4.5% raw fats, 12.4% cellulose, 20.8% dry matter and 1.5% ash. In another report, the fresh grapes marc contents were 0.5% digestible protein, 1.3% fat, 4.3 dry matter and 8% cellulose (Butt, 2002, Varis et al., 2004). A 100 kg fresh marc contained 2.5 kg carbohydrates. Grapes marc is rich source of organic and inorganic substances. The organic substances forming humus, nitrogenous substances, and phosphoric acid and potassium compounds are found in the grapes marc which is assumed as natural fertilizer source. The grapes marc contains more nitrogen and potassium compared to farmyard manure. During fermentation, grapes marc liberates high energy raising the temperature 78-84°C. The chemical constituents of marc are difficult for biological breaking down by the action of bacterial activities; thus, they are not benefited as much as farm yard manure or other inorganic substances (Bayraktar, 1973).

Straw bales

In wheat grown areas, if there are less available peat and/or perlite material, straw bale culture has provided its effectiveness to grow the vegetables under glasshouse conditions (Figure 3). Experiments revealed the fact that greenhouse production by using straw bales has many advantages over the cultivation of normal soils where soil-born diseases seriously limited the productivity. The system of straw bale culture provides a rooting environment free of diseases for healthy roots growth and consequently, for satisfactory development of the entire plant (Butt et al., 2004). This method was employed, for the first time, in Holland and Western Germany for the production of cucumbers and positive results were found. A wide application of straw bale culture was adopted in Israel, USA and West European countries. However, the most frequent use of this method was reported in Bulgaria, Canada and South Africa. In Turkey (Denizli Sarayköy), this system was experimented under geothermal heated glasshouse and encouraging results were achieved. However, the high cost of bales and their hard availability were the limiting factors (Sevgican, 1999 b). In England, since 1956, the vegetable crops, particularly greenhouse tomato and lettuce have been growing using the method of straw bale culture (Altıntaş and Variş, 1992). The use of straw bales was quite popular a few decades ago as a soil less medium because of low cost. The attraction of the use of straw bales decreased as new and better substrates became available in the market. Even today straw bales can be used by the grower using a low-input cropping system. The important features of straw bale culture are (Papadopoulos, 1994):

- The decomposed/fermented bales provide a bit high temperature to media; thus, prove successful results for roots development.
- Straw provides excellent aeration for root growth and ample space for root development.
- The ready seedlings when planted on the straw bales experience the process of photosynthesis more efficiently because straw material releases CO_2 with beneficial effect on productivity.
- During the process of fermentation in the straw material, a natural process of sterilisation occurs that provides a good start to the crop grown in the greenhouse The main reasons for the recent decline in the use of straw bales as a substrate are:
- More time is needed to prepare the straw bales.
- The difficulties in controlling the speed and timing of the fermentation.
- The bulkiness of the medium makes it difficult to manage.
- The high labour requirement in handling the bales.

Figure 3: Straw bales (wheat residues) can have efficient use for crop production in the country

COMMERCIAL USE OF SUBSTRATES

It is reported that the vegetable production can be improved by using various substrates of soil less culture. Therefore, the two important vegetable crops, tomato *(Lycopersicon esculentum* Mill*.)* and lettuce (*Lactuca sativa* Lin.) are being grown extensively all over the world in different growing media (Figure 4; Table 2 to 5). Both of these crops provide essential minerals and vitamins that are important for human diet (Martinez and Abad, 1992). The fresh tomato has been a component of the salad. Nutritionally the tomato is about 93% water and has only traces of fats and starches. Tomatoes provide micronutrients, a little fiber, and useful amounts of folic acid and are a good source of carotene and vitamin C (The West of Scotland Agric. College, 1988).

Table 2: Data indicating lettuce production in different substrates (Butt, 2001)

Substrate	Feature			
	Head (cm)	Weight (g)	Height (cm)	Leaves (number)
Soil mix	10.41	629	34.96	57
Perlite	11.63	756	35.16	60
Straw bales	11.33	665	33.23	61
Grapes residue	9.80	513	30.28	57

Figure 4: Stages of lettuce (left) and tomato (right) development in various growing substrates

In the arid regions, such as the Persion Gulf and Arab oil-producing states, growing of greenhouse crop in soil less substrates, especially for the production of tomatoes (Figure 5), cucumbers and lettuce are very much common, as they have limited arable land (Encarta Encyclopedia, 1996).

Table 3: Physical characteristics of tomato grown in different substrates (Butt, 2001)

Substrate	Feature			
	Soil mix	Perlite	Straw bales	Grapes residue
Flowers (number)	29.29	35.17	32.40	31.83
Fruit earliness (days)	120	122	121.0	120.0
Total fruit per plant (number)	14.0	18.0	18.00	9.00
Total fruit weight per plant (kg)	1.57	4.34	3.97	1.69
Single fruit weight per plant (g)	109	244	234.0	184
Single fruit diameter (cm)	6.56	8.45	8.14	7.25

Table 4: Chemical characteristics of tomato grown in different substrates (Butt, 2001)

Substrate	Feature			
	Soil mix	Perlite	S/bale	Grapes residue
Fruit juice pH	4.21	4.32	4.28	4.33
TSS of fruit (%)	7.07	4.06	4.52	4.39
Total acidity (%)	0.70	0.38	0.46	0.42
Dry matter contents (%)	8.19	4.65	5.23	5.30

Table 5: Organoleptic evaluation of tomato grown in different substrates (Butt, 2001)

Substrate	Feature			
	Soil mix	Perlite	Straw bales	Grapes residue
Fruit colour	4.37	4.34	4.31	3.90
Fruit firmness	3.91	4.00	4.21	4.16
Fruit flavour	4.06	3.83	4.23	3.58
General likeness	4.10	4.06	4.23	3.91

Figure 5: Size and quality of lettuce and tomatoes grown in various soil less growing substrates

THE SECRET OF PROSPERITY

The use of new growing substrates for crop production has brought dramatic prosperities in many countries by adopting modern trends and innovative ideas of production. The use of new substrates lead to alleviate the poverty ,efficient land utilization, potential source of foreign exchange, boosting food processing industry and strengthening country's economy. The use of growing substrates in horticulture would also lessen the burden of agronomic crops, sustaining the conventional horticultural production and contributing enormously under high population rise. The trend of urbanization & industrialization has enforced our country to utilize the indigenous resources to cope up existing food/crop shortage as well as for reduction of import pressure.

Above all the use of such substrates cause no land degradation, minimum chances of environmental pollution, economical to water consumption, easy to control the plant nutrients, early fetching of crops, no/nominal expenses of media sterilization and no gap is required after harvesting the crop. The pure water culture/hydroponics is gaining momentum all over the world for commercial crop production in horticulture. Presently one of the systems adopted is NFT (Nutrient Film Techniques) that requires principally the maintenance of pH and EC along with the sustainability of climatic conditions in the greenhouse (Figure 6) (Butt, 2003; Butt, 2005; Butt, 2007 a; Butt, 2007b)

Figure 6: NFT system in hydroponics/soil less culture technology. An interesting growth of nuclear seed of potato is seen in the extreme left. Seedlings were produced in tissue culture laboratory by employing meristem culture techniques. The idea of Bioponics (a word coined by the principle author derived from Biotechnology and Hydroponics) can take enormous benefit even for the crop grown under the soil and low yielding through conventional method of crop production in the soil (Butt, 2001)

SUGGESTIONS

- The trend of the use of various organic and inorganic media has gained a special attraction all over the world. This trend is in preliminary stage in the third world where there is a need to achieve net consequences of the undertaken trials dealing with the use of different substrates. The subsequent induction of these trials to modern farming community for commercialization would share, undoubtedly, a substantial part in economy of Pakistan.
- The sources of plant growing substrates such as straw bales, sand, gravels, sawdust, shredded bark, citrus marc, grapes marc etc. are conveniently available in abundant quantities in the developing countries. By developing the standardized growing techniques through close system of production, consequently, these sources can be taken into for best utilization. The production of crops through soil less culture is realized to be the need of the hour.
- Pakistan has got a diversity of climate, possessing competitive and lucrative horticultural crops. Similarly vegetable forcing in Pakistan is being developed steadily because of demand for fresh produce out of the normal season of production. In some regions, it is adopted where the season is too short for warm or cold conditions. To be successful, greenhouse growers must produce the crops when the outdoor supply is limited or they must produce quality products that may have commercial premium price (Butt and Al-Haq, 1993). The implication of crop production adopting soil less culture has prospective impacts to share the country’s economy provided, the incurred investment for soil less culture be considered on the grounds of yield and favorable environmental impact
- Pakistan is facing a serious population explosion with a total of 160 millions. This unexpected outgrowth of population, in turn, would reduce to great extent the cultivated land, consequently, the spreading of urbanity and industrialization. This prevailing condition must be realized and intensive cultivation with the trend of glasshouse industry is virtualized to cope with the lined-danger situation.

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