Green manure practices in intensive vegetable farming systems

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Abstract

Unchanged fast growing population in many tropical countries is reason for enormous increasing demand for food, but leads at the same time to irrevocable loss of arable land due to rapid urbanization (PCARRD, 1984). Expanded food production through opening up new agricultural land was still possible during the last decades, but further augmentation through deforestation and improper use of marginal locations will result in a dramatic loss of natural resources which cannot be tolerated (FRIEDRICHSEN, 1993). The future need is, therefore, to produce more food on existing land by an increase of productivity per unit area (ENGELHARDT, 1993; GOVINDEN et al., 1984). In vegetable production, intensified production goes very often hand in hand with pollution of the environment, especially through over-use of fertilizers and pesticides. One attempt to maintain a high level of productivity, but protect for further destruction of natural resources in more and more highly specialized, spatial limited vegetable production systems is to reconsider "alternative" ways of fertilization and soil protection, through the use of organic manuring, and - in particular - green manuring techniques. Numerous systems involving these practices are traditionally known; others were developed recently, and have not only introduced to vegetable farming. A balance of the

several benefits and constraints will be decisive on the long term if some of these techniques are able to meet the demands of the future.

1. Introduction

After end of the Second World War, a rapid increase of use of synthetic (N) fertilizers in vegetable farming has led to a high degree in specialization. In this context, specialization means that most of the vegetables are grown by farmers with most or all of their income deriving from the sale of their produce using almost exclusively synthetic fertilizers (KELLY, 1990). Old traditional practices such as green manuring were neglected since then, and it seems as if the newly introduced high yielding varieties (HYV) are difficult to be grown without high off-farm inputs (PHATAK, 1992). Due to low costs, over-use of inorganic sources has become a serious problem in world agriculture. Just to give an idea of how serious over-fertilization has already affected natural soil resources in intensive vegetable farming in Taiwan, the following examples: Already in 1973, ANONYMOUS warned of podsolization, erosion, and acidification following excessive fertilization in Taiwan's agriculture. For the cultivation of vegetable soybean, farmers usually apply as much as 10 times more than the recommended fertilizer rates (HUNG et al., 1991). A survey undertaken in Taiwan's most important vegetable production area (Changhua county) for the crops pea, cabbage, eggplant, and Chinese chive showed that on average farmers apply fertilizers at rates up to several times (N: 132-493 %, P: 68-253 %, K:135-284 %) higher than the recommended input (HUANG et al., 1989). The study showed that the originally neutral to slightly alluvial soils in these regions have changed to slightly and strongly acidic (below pH 5.5) soil reaction, particularly in surface layers. The authors conclude that "the over-dose of fertilizer might be the main reason of soil acidification and salination".

Recently, agricultural research started trying to (re-) consider alternative ways of fertilizing vegetables in order to (1) conserve fossil oil, (2) reduce ground water pollution, (3) reduce the risk of high nitrate levels in vegetables, and (4) conserve soil resources (KELLY, 1990). In this respect, "alternative ways of fertilizing" does not necessarily mean to substitute all use of inorganic sources, it should rather express: substitute for at least a part of the common application rates, and prevent the serious effects of excessive over-fertilization. Detection of suitable green manure practices plays a major role in this process.

2. Organic Farming

Under consideration that profit has to remain an integral part in vegetable farming, alternative (organic) N sources are, for example (KELLY, 1990):

- Industrial by-products (e.g. sugarcane molasses)
- Animal manure (from feed lots, poultry farms, horse stables)
- Municipal composting
- Green manure

Major problems of organic fertilization are the content of for vegetables readily available biological nitrified N, sufficient supply, distance of farm from supplier, and availability of technical equipment for transport and application. Besides that, accurate timing of the right amount of manure means considering manure material, crop, climatic conditions, and mode of application (KELLY, 1990).

WARE & JOHNSON (1945) were testing single and combined applications of fertilizers, animal manure, and green manure to several vegetable crops on a light, sandy soil low in organic matter. Results go well hand in hand with other similar examinations indicating that:

- Vegetables grown in sandy soils respond positively to addition of organic matter
- Under low or no rates of fertilizer input, organic manure has the potential to increase crop yields dramatically
- Animal manure will probably exert a greater effect than green manure
- Positive effects of green manure are likely to occur delayed
- Additional N fertilizer to green manure will probably increase yields

3. Green Manuring

3.1. Benefits and Constrains

The potential benefits of green manure for soil improvement and soil conservation in vegetable cropping systems are very likely not to be achievable without acceptance of negative side effects and technical difficulties (ADAMS, 1966; HOYT & HARGROVE, 1986; KELLY, 1990; MANNERING & MEYER, 1963; PHATAK, 1992; SARRANTONIO, 1992; SITOMPUL ET AL., 1992; SUKMANA & SUWARDJO, 1991; SUR ET AL., 1992; YIH, 1989):

Positive effects embrace:

- Build up soil organic matter, enhance soil physical and chemical properties
- Retard soil degradation, and soil erosion
- Act as a source of biological fixed N (legumes)
- Conserve nutrients
- Make some nutrients (such as K) more available
- Make N fertilizers more efficient by recycling
- Attract beneficial organisms
- Control harmful insects and pests
- Break up dense soil layers, retard soil compaction
- Increase water percolation (infiltration), and movement of excess water through an increased number of pore spaces, reduce water run-off velocity
- Lowering soil temperature in hot climates, reduce seasonal and daily fluctuations in soil temperature
- Reduce evaporation (as mulch)
- Control weed infestation

Potential negative effects are:

- Depletion of soil moisture
- Lowering soil temperature in moderate climate
- Allelopathy
- Attraction of harmful organisms
- Competition with primary crop.

At the same time, green manuring practices raise several technical difficulties:

- Selection of suitable species
- Management of those species
- Timing
- Spacing
- Additional labor, input, expertise.

3.2. Spacing

Green manure as a means of vegetative soil conservation can be **spaced** (A) externally (outside of the production area), and applied to the production zone as a mulch. (B) Internally spacing embraces growing green manure as a (1) strip (barrier) or (2) alley (hedgerow) besides the field, and growing them as a (3) full crop within the field.

Over time, soil improving crops (SICs) grown as a full crop can be introduced into a vegetable cropping sequence as a (1) pre- or succeeding crop, as a (2) relay-intercrop, or as a (3) full intercrop.

Externally

Application of externally produced organic mulches affects crop growth by influencing weed growth, soil conditions, soil nutrient status, and soil erosion: If weeds are likely to reduce crop yields, organic surface mulches might be able to suppress their growth by hindering and delaying germination (emergence) through shading. On the other hand, mulch may enhance soil conditions for plant growth in general so that also weeds are favored (YIH, 1989). Limited time for mulch decomposition is reason for the fact that mulch favors crop growth by enhancing soil physical conditions rather than by adding nutrients (YIH, 1989).

The positive effects of surface mulches on soil erosion, water runoff and nitrogen loss are well stated (SUKMANA & SUWARDJO, 1991), so that there is a need to examine the minimum quantity of mulch which will be effective in controlling erosion (ADAMS, 1966; MANNERING & MEYER, 1963), and the mode of application (e.g. band placement) if material is limited (SUR ET AL., 1992).

Internally

Within a vegetable production area green manure crops may be introduced as barriers which have proofed to be effective in soil and water conservation on sloping land (traditional bench or ridge terrace constructions in Indonesia; SUKMANA & SUWARDJO, 1991). In the way water infiltration into the soil is enhanced, eroded soil material can settle along the strips, and is protected for loss.

Another traditional use of green manure within crop production areas is the alley or hedgerow cropping system which means by definition "cultivating annual crops in between rows of perennial plants" (SITOMPUL ET AL., 1992). Generally, but not necessarily, these hedgerows consist of leguminous trees which are periodically pruned during the growing season to prevent shading, to reduce competition with the primary crop, and to produce a surface mulch or green manure in order to contribute nutrients to the associated crop. This system is long time known in Indonesia as an economically and ecologically sustainable agricultural production system with limited use of external inputs (SITOMPUL ET AL., 1992). Demands that have to be put on a suitable hedgerow green manure species embrace: a deep root system for recycling otherwise leached nutrients, ability to fix gaseous nitrogen, adaptation to local environmental conditions, and ability to survive regular cuttings.

3.3. Timing

Temporary

When to grow green manure in rotation with vegetables, it is difficult to plan this extra crop into these intensive systems. Therefore, timing plays a crucial role.

For soil rehabilitation, particularly legume green manure cover crops are an effective mean to recover nearly cleared or degraded land (SUKMANA & SUWARDJO, 1991). Although there might not be a short term benefit for the farmer, the green manure may have other positive effects such as reclaiming weed infested land (SUKMANA & SUWARDJO, 1991). As a winter cover crop in temperate climate, green manure is grown at a time when it is not possible to grow a market crop.

Following the completion of vegetable harvest, green manure can act as subsequent crop in a rotation system (SARRANTONIO, 1992). In a more intensive way, green manure can be over-seeded into the vegetable as a relay-intercrop, or the vegetable can be sown/planted into the matured green manure.

Permanently

When continuously grown as a full intercrop (living mulch) within vegetables, there is a need to check the vigor of the green manure to avoid competition. SARRANTONIO (1992) mentioned in this respect a permanent bed system where living mulches are located on the edges of the beds to minimize its interference with the market crop..

Figure 1 summarizes the possibilities of introducing manure into vegetable cropping systems.

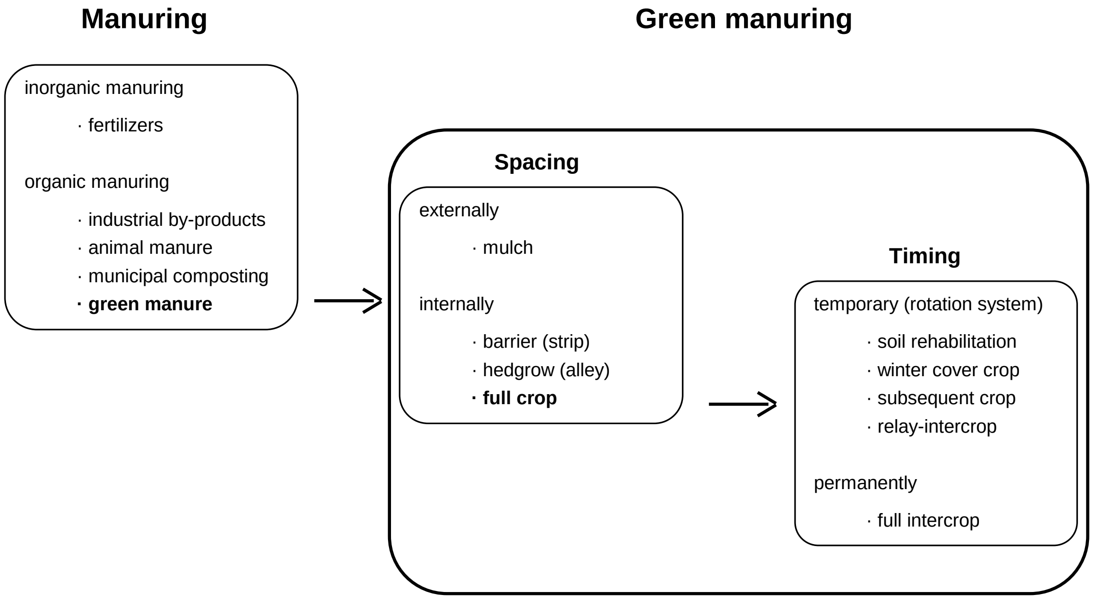

Figure 1. Use of manure in vegetable cropping systems.

3.4. Temporary Green Manure (Rotation System)

Numerous investigations have been undertaken in order to introduce green manure as out-of-season crops into crop sequences when the market crop cannot be grown during a specific time of the year, e.g. during winter in moderate climate. In most cases, leguminous species are sown to make use of the additional benefits of biological nitrogen fixation. In addition to already mentioned effects on soil conservation, there are several other demands on a green manure cover crop in rotation with market (vegetable) crops. In this respect, a suitable green manure species should (HOYT & HARGROVE, 1986):

- Supply succeeding crops with maximum amount of decomposable material
- Influence soil N and microbial activity positively
- Release highly available nitrogen with positive growth response to the crop
- Conserve soil moisture when used in mulch tillage systems
- Not deplete soil moisture in arid regions

In moderate climate, a green manure crop can be produced during winter without sacrificing cash crop production, but its effect on crop yield is dependent on management practices, climate, soil, and particularly species of green manure and crop (RADKE ET AL., 1988).

<u>Management</u>

Management of a well-chosen species which is adopted to local climatic and environmental conditions embraces - probably difficult (WALLACE & BELLINDER, 1992) - interseeding techniques for early establishment (to achieve vigorous seedling growth), and killing techniques if the green manure is not to be incorporated before the first spring vegetable crop (FRYE ET AL., 1988). To provide a surface mulch it is necessary to kill the cover crop with herbicides in order to prevent it from competing with the vegetable crop. Preplant killing of premature green manure offers the advantage of making stored water quickly available, and adding a greater N concentration to the main crop. Postponing killing is advantageous in terms of adding a greater amount of dry matter (FRYE ET AL., 1988). Seeding or planting into mulches may, however, reduce crop stands due to release of chemical compounds by the decomposing residues (WALLACE & BELLINDER, 1992). It is also important to mention that there are differences in the timing of N availability of mulching vs. incorporation techniques. Especially in the case that the green manure is mulched and not incorporated, the release of crop available soil ammonia is expected to occur delayed (FRYE ET AL., 1988; SHENNAN, 1992).

Biological effects

Positive effects on soil water by out-of-season cover crops are achieved by an increase in soil organic matter which is an important mean to effectively stabilize soil structure (WAGGER & MENGEL, 1988). Therefore, planting the spring crop no-tillage into a mulched cover crop has proved superior over conventional tillage without green manure (winter) cover crop (FRYE ET AL., 1988). This can be attributed to reduced evaporation from the covered surface until the time that the primary crop closes and transpiration exceeds evaporation (FRYE ET AL., 1988). In this respect, however, it is questionable if this reduction of evaporation may compensate for possible soil water depletion during the growth period of the green manure. WAGGER & MENGEL (1988) conclude that in limited rainfall areas, winter cover cropping is not adequate because of the need to conserve soil moisture for the main crop. Other investigations (BADARUDDIN & MEYER, 1989) show that a properly chosen green manure species may not deplete significant more water than fallow.

It is well known that including legume green manure in a cropping sequence can enhance productivity of succeeding cash crops through effects on soil nitrogen. This can not only be attributed to contribution of biological fixed nitrogen (e.g. UTOMO ET AL., 1992) alone, other effects such as improvement in soil structure etc. are summarized as "rotational effects" (HESTERMAN, 1988), or "increased N-cycling" within the system, where an increase in active soil organic matter and microbiological activity might require relatively less N inputs to the system (RADKE ET AL., 1988).

N contribution of legume green manure widely depends on (1) species, (2) environment, (3) succeeding cash crop, (4) management practices, (5) time of incorporation/mulching (HESTERMAN, 1988; RADKE ET AL., 1988), but as a general guideline it can be said that only a percentage of N build in the legume will actually be available, or will be able to be absorbed by the following crop (HESTERMAN, 1988). The larger part is incorporated into soil organic matter and inorganic N pool either to become available to a second crop (REDDY ET AL., 1986B), or to be lost by denitrification and leaching (HESTERMAN, 1988), especially when winter-killed (RADKE ET AL., 1988). Therefore, the "N-Fertilizer Replacement Value" (FRV) expresses the benefit of a legume green manure in a cropping sequence as it measures the equivalent amount of N fertilizer required to produce the same yield as a crop without preceding legume crop (FRYE ET AL., 1988; HESTERMAN, 1988; RADKE ET AL., 1988). Estimations of nitrogen fixation, N contribution to succeeding non-leguminous crops, FRV, and residue-N availability values were estimated for a large variety of legumes and crops. In summary, a legume green manure crop may contribute 18-390 kg N/ha to a succeeding crop with up to 88 % of this nitrogen deriving from biological fixation. This N contribution may replace 24-176 kg fertilizer-N/ha with a residue-N availability percentage of 10-34 % (CADISCH ET AL., 1989; HESTERMAN, 1988; HUBER ET AL., 1987; RADKE ET AL., 1988; RENNIE, 1984; SHENNAN, 1992; UTOMO ET AL., 1992). In this respect, FRIBOURG & JOHNSON (1955) found a highly significant (r^2=97,6 %) linear relationship between N-yields and legume plant dry matter yield independent of location (4), season (2), and legume species (6) investigated.

Several authors investigated winter green manure - summer cash crop sequences where the cover crop was able to provide all the N required to produce maximum yields in the subsequent crop (HESTERMAN ET AL., 1986; RADKE ET AL., 1988), where yields were equivalent or even better in the green manure treatments than those obtained under optimum fertilizer regime following winter fallow (BADARUDDIN & MEYER, 1990; SHENNAN, 1992), and when crop yields increased linearly with increased amounts of produced green manure N (REDDY ET AL., 1986A; REDDY ET AL., 1986B). Other investigations come to the conclusion that winter cover crops are not likely to add any N to the cropping system (KELLY, 1990), and that additional, moderate N fertilizer applications are necessary to improve productivity (UTOMO ET AL., 1992). As the legume cover crop cannot provide sufficient N to produce optimum yields of following non-leguminous crops, there is at least the chance to lower application rates of supplemental N fertilizer appreciably (FRYE ET AL., 1988).

The usefulness of cover cropping between periods of regular crop production periods has been particularly emphasised for <u>tropical regions</u> (HAIRIAH & VAN NOORDWIJK, 1987; HAIRIAH ET AL., 1992; UTOMO ET AL., 1992):

In an environment with high risk of soil erosion and quick depletion of soil fertility due to excessive rainfall, low soil organic matter content, and high weed infestation potential, a cover crop should at least partially compensate for nutrients (1) removed by the harvested crop, and (2) lost due to leaching. Wanted characteristics of a legume cover crop in a tropical environment to help maintaining soil stability and fertility are:

- Rapid establishment
- High biomass production
- Good nodulation, and N fixation
- Good soil cover
- Good weed control
- Deep reaching and abundant branching root system

Winter cover crops must not necessarily consist exclusively of legumes. For <u>non-leguminous cover crops</u> it is particularly the residue C/N ratio which governs whether the crop acts as N source or sink to the succeeding cash crop (WAGGER & MENGEL, 1988): Cover crops with high C/N ratios could negatively affect N availability through competition or immobilization, but could also prevent for leaching losses and ground-water pollution.

3.5. Permanent Green Manure

Cover crops that are interplanted with the main crop are defined as living mulches. Growing mulches on the same piece of land, and at the same time a cash crop is grown is particularly interesting in that rapid increases in rate of urbanization and rapid decrease in agricultural land have drastically reduced fallow or green manure periods to restore soil fertility. Use of living mulches may, therefore, stabilize fertility under intensive land use (AKOBUNDU & OKIGBO, 1984).

Commonly used green manures are perennial leguminous species, but also grasses find distribution. According to the live mulch theory, the permanent strips or rows should (BUGG ET AL., 1991; ELKINS ET AL., 1979; ILNICKI & ENACHE, 1992; PHATAK, 1992; REDDY ET AL., 1986A; SARRANTONIO, 1992):

- Suppress weeds by blocking light
- Use up resources that weeds would otherwise use
- Protect against soil compaction, restore soil structure
- Control erosion
- Decrease fertilizer requirements by preventing leaching
- Enhance moisture or nutrient retention
- Decrease pesticide requirements by controlling pathogens biologically
- Add biologically fixed nitrogen, and organic matter

Living mulch in corn production

Intensive corn production with conventional tillage practices is known to cause serious erosion problems (e.g. in the Midwest of the U.S.). Alternative minimum and no-tillage practices in corn production have, therefore, been developed to overcome soil degradation.

The major problem accompanying minimum tillage practices is weed control (ENACHE & ILNICKI, 1990). As living mulch is utilized to suppress weeds in minimum tillage systems, it also competes with the cash crop. To avoid this interspecific competition, living mulches must be killed or suppressed regularly, especially during critical growth stages of the main crop (ILNICKI & ENACHE, 1992). In this respect, several studies examined the feasibility of producing good maize yields while maintaining adequate mulch cover for erosion and weed control:

Without destruction of natural vegetation, corn might be sown in grass sod if additional irrigation is available to avoid excessive competition for water in dry seasons, and if the grass is regularly suppressed by use of herbicides (ELKINS ET AL., 1979). When live mulches are to be established into maize stand, a wider row spacing of corn might be required to enable survival of the initially slower growing green manure, but corn yields are expected to decrease with lower plant densities (PENDLETON ET AL., 1957). Competition for soil water in dry regions or dry seasons can be avoided by use of additional irrigation, or regular clipping to keep the plants small and thereby reduce its water use (PENDLETON ET AL., 1957).

Experiments with perennial legumes as living mulch (e.g. Alfalfa, Centrosema) tested (1) timing of intersowing legume (or maize), (2) different rates of mulch suppression, (3) different rates of weed suppression, and (4) different rates of additional irrigation. Results show that (AKOBUNDU & OKIGBO, 1984; BOX ET AL., 1980; EBERLEIN ET AL., 1992):

- Competition for water is likely to be the most important factor limiting corn production
- Weed control may still be required irrespective of the type of living mulch used
- Growth of living mulch especially during early plant stages of maize may reduce yields substantially
- Competition for nutrients may result in deficiency symptoms and poor establishment of corn seedlings
- It is not only competition for soil water and plant nutrients that limits the use of annually killed mulch that is allowed to regrow.

To resolve problems of establishing a suitable living mulch - maize crop system, ENACHE & ILNICKI (1990) come to the conclusion that an ideal living mulch might be a winter annual legume that completes its life cycle before the demand for growth factors of the main crop is greatest, and competition is expected to be most severe. By way of exploiting a niche in time, the unusual life cycle of subterranean clover ("subclover", *Trifolium subterraneum* L.) allows for maximum corn yields under Mediterranean climatic conditions (summer hot and dry; winter cold and wet) by its effectiveness in weed control, especially on the long term, and the avoidance of competition during critical growth stages of the main crop (germination in late summer - vegetative growth in autumn - dormant in winter - generative growth spring to summer - death late summer; ILNICKI & ENACHE, 1992; LANINI ET AL., 1989).

<u>Living mulch in vegetable production</u>

Elimination of rotation or green manure fallow periods through highly specialized and intensified production is particularly obvious in vegetable farming systems, and has initiated - more or less successfully - research on the use of permanent living mulches (NICHOLSON & WIEN, 1983). Investigations have been undertaken to proof the usefulness of permanent cover cropping in (1) controlling pest incidence, and (2) improving soil conditions.

<u>Cultural control of pests</u> by use of permanent living mulch way work through the biological activities of complementation (cover crop acts as a "better food" for a parasite), and facilitation (cover crop helps sustain beneficial predators) (BUGG, 1992). Living mulch of several clovers, other green manure legumes, and grasses has been tested for its ability to control pest attacks as trap crops. BUGG ET AL. (1991) relay-intercropped cover crops with cantaloupes, ANDOW ET AL. (1986) grew cabbage with living mulch, and both investigations came to the same result that reduction of phytophagus insects was obvious, but this positive effect was offset by yield reduction from competition with the living mulch. Therefore, establishment of living mulch as insectary traps in vegetable farming systems is very limited because of excessive competition which could be resolved by relay-intercropping schemes (BUGG, 1992), or by a distant row field arrangement (BUGG ET AL., 1991). Introduction of these systems requires considerable management skills (ANDOW ET AL., 1986), but could find

its role in cases, when use of pesticides is not possible (if no effective pesticide is available), or not recommended (e.g. before crop harvest; HOKKANEN, 1991).

Most attempts to use living mulch in vegetable farming systems for resource conservation and soil improvement have been successfully only upon intensive mechanical or chemical suppression. For a living mulch system, where growth of SICs was not regulated, NICHOLSON & WIEN (1983) screened a number of turfgrasses and clovers for their possible role in sweet corn and cabbage crops and found a highly significant negative correlation between vegetable yield and mulch dry weight, irrespective of mulch species tested. Drought stress symptoms were evident in the sweet corn crop, and for cabbage, maturity of heads was delayed, and marketable yield was significantly reduced by an assumed competition for light, N, and water during peak growth. This indicates that it might be impossible to grow a vegetable with living mulch at the same time and in the same place without sacrificing crop yields. Also WILES ET AL. (1989) concluded for a living mulch system of Pak Choi and rygrass that suppression of mulch growth is crucial to minimize competition: Variation of vegetable and mulch seeding rate had no effect on the extent of yield reduction, and, therefore, does not appear to be feasible to limit competition. If the competitive ability of a living mulch species is only correlated with its presence and its demand for resources in time rather than its actual demand for quantity of resources, it is a question of time of sowing in, timing and frequency of suppression, and continuous supply of resources to develop a suitable living mulch system.

To overcome competition between vegetable and living mulch, SARRANTONIO (1992) mentioned possible relay-intercropping schemes of tomato and hairy vetch (*Vicia villosa* Roth.), cereal rye (*Secale cerale* L.), and annual ryegrass (*Lolium multiflorum* L.) if the living mulch is regularly mowed.

Utilization of the unusual life cycle of subterranean clover showed promising results in grain corn due to its effectiveness in weed control (ILNICKI & ENACHE, 1992). The same investigation undertaken with vegetables showed, however, that lower weed biomass is not automatically related to higher crop yields, that means positive effects of reduced weed incidence on crop growth is likely to be offset by interference with the subclover living mulch. For tomato and snapbean, crop yields were equal to the control with conventional tillage and herbicide use due to effective weed control provided by the living mulch. Mowing the subclover prior to planting was, however, necessary to avoid yield reduction in cabbage and sweet corn. Finally, highest yields of squash and soybean were achieved in the checks where herbicides were used for weed control. The combined use of mowing and herbicide appeared to be necessary for growing lettuce with subclover living mulch, and killing the mulch completely with herbicides before lettuce planting provided increased seedling growth (LANINI ET AL., 1989).

Analyzing competition between vegetable crops and green manure living mulch

Competition as defined by the competitive production principle (VANDERMEER, 1981) consists of intraspecific competition (interactions between organisms of the same species) which is basically a plant density effect, and can easily be measured by systematic variation of crop plant densities (HUXLEY and MAINGU, 1978; VANDERMEER et al., 1984; VEEVERS & ZAFAR-YAB, 1980), and interspecific competition (interactions between different species), which depends on (1) total plant density, (2) proportion of each species, and (3) spatial arrangement of the species relative to each other (RADOSEVICH ET AL., 1986). Possible mechanisms of interspecific competition are (GLIESSMAN, 1986; RADOSEVICH ET AL., 1986): (1) coexistence (no interaction), (2) one side interactions (one species facilitates/inhibits the performance of the second species), (3) antagonism (two way negative interaction), and (4) symbiosis (two way positive interaction).

According to the competitive exclusion principle or interference production principle, 2 species with identical demands on growth factors cannot exist side by side. Thus, coexistence of 2 species is only possible through formation and occupation of different ecological niches (GEISSLER et al., 1981; ROSSET et al., 1984; VANDERMEER, 1981). If the 2 species deplete growth factors in different niches, one competitor modifies the environmental factors of the other individual, "competition" is, therefore, the sum of reactions of individual species upon the modified environmental factors caused by the associated species (DONALD, 1963).

The sink-and-source theory explains competition as a movement of growth factors along concentration gradients, from "rich centers" towards depleted centers. In this respect, competition begins when the supply of necessary factors falls below the combined demands of both species (DONALD, 1963), when the species have to share limited environmental resources (BREESE & HILL, 1973).

Competition is likely to occur for the growth factors water, nutrients, and light, but there can be no competition for space (DONALD, 1963). The ability of a species to exploit these environmental conditions to a certain amount (quantity) and at a certain rate (in time) will decide about its success over competitors. There are strong interactions between availability and crop demand of the different growth factors (DONALD, 1963): Under low fertility regime, competition will be for soil nutrients, and when water supply is limited, competition will be for soil water, but if nutrients and water are available in adequate supply, light will become the sole limiting factor. Even if a living mulch is a strong potential competitor for water and nutrients, its capacity to compete for water and nutrients may be greatly reduced if the main crop heavily shades the mulch. In other words, it is the availability of the most limiting factor (minimum factor) which is decisive for a crops demand for the other (non-limiting) growth factors.

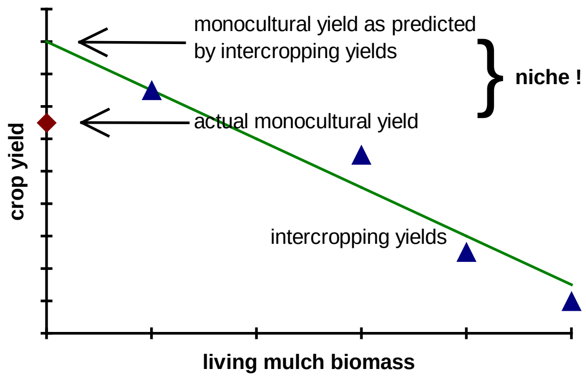

Figure 2. Indication of complementary (niche) effects in a vegetable - living mulch system (according to BREESE & HILL, 1973)

Although competition for the different growth factors has quite different consequences, simple equations could be a helpful mean to express general competitive ability of associated species (BREESE & HILL, 1973; DEW, 1972). Complementary or occupation of slightly different niches in time or space within a living mulch - vegetable system is then indicated by a higher predicted monoculture performance from regression equations only calculated by using intercropping yields, than actually achieved monocultural yields (figure 2).

4. Summary and Conclusions

Food production has to be increased by 40 % during the next 15 years to feed the continuously growing world population (ENGELHARDT, 1993). Reclamation of new agricultural land has become almost impossible so that productivity on existing areas has to be increased. Intensified production on vegetable farms is very often related to destruction of natural environmental resources not only by excessive over-fertilization. Green manure technique as an "alternative" way of fertilization may not only substitute for at least a part of the inorganic inputs, but may also lead to long-term stability and sustainability of the more and more spatial limited production zones.

In general, organic manuring raises one basic difficulty in comparison to exclusive use of inorganic fertilizers: Speed of release and total amount of plant available nutrients are difficult to estimate. The reaction of crops on organic manure has been proofed particularly positive on poor sites (sandy soils with low organic matter content; WARE & JOHNSON, 1945), or in cases where inorganic fertilizers are not available (HESTERMAN, 1988). The beneficial effects such as increased "inner cycling of nutrients" are likely to appear on the long term, and are, therefore, difficult to measure and proof. Negative short-term effects (e.g. water depletion or competition through living mulch) are, however, easy to determine.

Use of externally produced manure such as green manure mulch material raises technical difficulties in terms of availability, transportation, and application. Growing a green manure crop within the system as a part of the vegetable cropping sequence might be applicable under special circumstances (soil rehabilitation, reclamation of land, during non-cropping seasons), but under tropical year-round production conditions, it is difficult to plan a extra crop into the system (SARRANTONIO, 1992), and its highly questionable if the benefits (e.g. N supply for succeeding crops) are able to offset the reduction in crop acreage (KELLY, 1990). For substitution of inorganic (N) fertilizers it is to be expected that use of green manure crops will lead to long-term benefits (increased N cycling within the system, improved nitrogen-yield efficiency; RADKE ET AL., 1988), but "substitution of N fertilizer by legume cover crops may not offset seeding costs at present fertilizer costs" (FRYE ET AL., 1988), and "there is no clear evidence that utilization of legume N is more profitable than use of fertilizers" (HESTERMAN, 1988). KELLY (1990) concludes, that "more of such research is not needed".

Therefore, some attempts are going in the direction of growing green manure as a permanent intercrop (living mulch), side by side with the main crop. Long-term benefits are expected in corn production if short-term constraints are able to be managed through additional inputs (irrigation), cultural practices (suppression), and selection of suitable living mulch species (useful life cycles; subclover).

In vegetable production under tropical conditions, environmental problems are extremely serious (erosion, soil degradation), but to overcome them by use of living mulch, the primary demand is to reduce negative interference of the living mulch with the weak competitor vegetable. Investigations have shown a negative correlation of vegetable yields and living mulch biomass production, so that the use of living mulch e.g. for reduction in pest attacks will probably not lead to economic gains (HESTERMAN, 1988), and will be restricted to special cases (HOKKANEN, 1991). Timing and management of a full mixture cash crop - living mulch is "too labor-intensive for the low chance of success" (KELLY, 1990).

Avoidance of excessive competition between vegetable and cover crop might be, however, achieved by modification of spatial arrangement of the two crops relative to each other: The agro-forestry hedgerow cropping system in Indonesia has proofed to maintain the yield potential, and to improve productivity of cash crops (maize, soybean) if adequate management practices are applied (SITOMPUL ET AL., 1992). A modified system with non-wooden species could gain importance in permanent bed systems, where the living mulch is located in the furrows between the beds (SARRANTONIO, 1992). Finally, ADITYA (1993) mentioned a modification of the Indonesian sorjan cropping system in Bangladesh, where a (vegetable) legume is grown on the edges of the permanent high beds.

References

ADAMS, J.E. 1966: Influence of mulches on runoff, erosion, and soil moisture depletion. *Soil Sci. Soc. Amer. Proc*. 30, 110-114

ADITYA, D.K. 1993: Vegetable production and development in Bangladesh. Agricultural research project phase II (supplement). BARC/BARI-AVRDC-USAID project No. 388-0051. Asian Vegetable Research and Development Center, Shanhua, Taiwan

AKOBUNDU, I.O., OKIGBO, B.N. 1984: Preliminary evaluation of ground covers for use as live mulch in maize production. *Field Crops Res.* 8, 177-186

ANDOW, D.A., NICHOLSON, A.G., WIEN, H.C., WILLSON, H.R. 1986: Insect populations on cabbage grown with living mulches. *Environ. Entomol.* 15, 293-299

ANONYMOUS 1973: Lexikon der Geographie. Georg Westermann Verlag, Braunschweig

BADARUDDIN, M., MEYER, D.W. 1989: Water use by legumes and its effect on soil water status. *Crop Sci.* 29, 1212-1216

BADARUDDIN, M., MEYER, D.W. 1990: Green-manure legume effects on soil nitrogen, grain yield, and nitrogen nutrition of wheat. *Crop Sci*. 30, 819-825

BOX, J.E., WILKINSON, S.R., DAWSON, R.N., KOZACHYN, J. 1980: Soil water effects on no-till corn production in strip and completely killed mulches. *Agron. J.* 72, 797-802

BREESE, E.L., HILL, J. 1973: Regression analysis of interactions between competing species. *Heredity* 31(2), 181-200

BUGG, R.L. 1992: Using cover crops to manage arthropods on truck farms. *HortScience* 27(7), 741-745

BUGG, R.L., WÄCKERS, F.L., BRUNSON, K.E., DUTCHER, J.D., PHATAK, S.C. 1991: Cool-season cover crops relay intercropped with cantaloupe: influence on a generalist predator, *Geocoris punctipes* (Hemiptera: Lygaeidae). *J. Econ. Entomol.* 84(2), 408-416

CADISCH, G., SYLVESTER-BRADELY, R., NÖSBERGER, J. 1989: ^{15}N-based estimation of nitrogen fixation by eight tropical forage-legumes at two levels of P:K supply. *Field Crops Research* 22, 181-194

DEW, D.A. 1972: An index of competition for estimating crop loss due to weeds. *Can. J. Plant Sci.* 52, 921-927

DONALD, C.M. 1963: Competition among crop and pasture plants. *Advances in Agronomy* 15, 1-118

EBERLEIN, C.V., SHEAFFER, C.C., OLIVEIRA, V.F. 1992: Corn growth and yield in an Alfalfa living mulch system. *J. Prod. Agric.* 5(3), 332-339

ELKINS, D.M., VANDEVENTER, J.W., KAPUSTA, G., ANDERSON, M.R. 1979: No-tillage maize production in chemically suppressed grass sod. *Agron. J.* 71, 101-105

ENACHE, A.J., ILNICKI, R.D. 1990: Weed control by subterranean clover (*Trifolium subterraneum*) used as living mulch. *Weed Technology* 4, 534-538

ENGELHARDT, T. 1993: Die vernachlässigte Landwirtschaft in der Entwicklungszusammenarbeit. GTZ Abt. 423 Info Nr. 1/93. Deutsche Gesellschaft für Technische Zusammenarbeit, Eschborn

FRIBOURG, H.A., JOHNSON, I.J. 1955: Dry matter and nitrogen yields of legume tops and roots in the fall of the seeding year. *Agron. J.* 47, 73-77

FRIEDRICHSEN, J. 1993: Konzepte und Arbeitsbereiche. GTZ Abt. 423. Deutsche Gesellschaft für Technische Zusammenarbeit, Eschborn

FRYE, W.W., BLEVINS, R.L., SMITH, M.S., CORAK, S.J., VARCO, J.J. 1988: Role of annual legume cover crops in efficient use of water and nitrogen. Cropping strategies for efficient use of water and nitrogen. ASA Special Publication No. 51. ASA-CSSA-SSSA, Madison, USA

GEISSLER, E., LIBBERT, E., NITSCHMANN, J., THOMAS-PETERSEIN G. (eds.) 1981: Kleine Enzyklopädie Leben. VEB Bibliographisches Institut, Leipzig

GLIESSMAN, S.R., 1986: Plant interactions in multiple cropping systems. In: FRANCIS, C.A. (ed.): Multiple cropping systems. Macmillan, New York

GOVINDEN, N., ARNASON, J.T., PHILOGENE, B.J.R., LAMBERT, J.D.H. 1984: Intercropping in the tropics: advantages and relevance to the small farmer. *Canadian J. Dev. Studies* 5, 213-232

HAIRIAH, K., UTOMO, W.H., VAN DER HEIDE, J. 1992: Biomass production and performance of leguminous cover crops on an ultisol in Lampung. *Agrivita* 15(1), 39-43

HAIRIAH, K., VAN NOORDWIJK, M. 1987: Cover crops on acid soils. *Ileia* 3(1), 9

HESTERMAN, O.B. 1988: Exploiting forage legumes for nitrogen contribution in cropping systems. Cropping strategies for efficient use of water and nitrogen. ASA Special Publication No. 51. ASA-CSSA-SSSA, Madison, USA

HESTERMAN, O.B., SHEAFFER, C.C., BARNES, D.K., LUESCHEN, W.E., FORD, J.H. 1986: Alfalfa dry matter and nitrogen production, and fertilizer nitrogen response in legume-corn rotations. *Agron. J.* 78, 19-23

HOKKANEN, H.M.T. 1991: Trap cropping in pest management. *Annu. Rev. Entomol.* 36, 119-138

HOYT, G.D., HARGROVE, W.L. 1986: Legume cover crops for improving crop and soil management in the southern United States. *HortScience* 21(3), 397-402

HUANG, H.C., TSAI, Y.F., LAY, W.L. 1989: Studies on the soil retarded growth factors of vegetable farms in central Taiwan. *Bulletin of Taichung District Agricultural Improvement Station* 24, 63-70

HUBER, R., KELLER, E.R., SCHWENDIMANN, F. 1987: Effects of biological nitrogen fixation by faba beans (Vicia faba L.) on the nitrogen economy of the soil. *FABIS Newsletter* 17, 14-20

HUNG, A.T., CHENG, J.H., MA, C.H., KOBAYASHI, H. 1991: Effect of fertilizer management and rhizobia inoculation on yield and quality of vegetable soybean. In SHANMUGSUNDARAM, S. (ed.): Vegetable soybean: research needs for production and quality improvement. Asian Vegetable Research and Development Center, Shanhua, Taiwan

HUXLEY, P.A., MAINGU, Z. 1978: Use of a systematic spacing design as an aid to the study of inter-cropping: some general considerations. *Expl. Agric.* 14, 49-56

ILNICKI, R.D., ENACHE, A.J. 1992: Subterranean clover living mulch: an alternative method of weed control. *Agric. Ecosystems Environ.* 40, 249-264

KELLY, W.C. 1990: Minimal use of synthetic fertilizers in vegetable production. *HortScience* 25(2), 168-169

LANINI, W.T., PITTENGER, D.R., GRAVES, W.L., MUÑOZ, F., AGAMALIAN, H.S. 1989: Subclovers as living mulches for managing weeds in vegetables. *California agriculture* 43(6), 25-27

MANNERING, J.V., MEYER, L.D. 1966: The effects of various rates of surface mulch on infiltration and erosion. *Soil Sci. Soc. Amer. Proc*. 30, 84-86

NICHOLSON, A.G., WIEN, H.C. 1983: Screening of turfgrasses and clovers for use as living mulches in sweet corn and cabbage. *J. Amer. Soc. Hort. Sci.* 108(6), 1071-1076

PCARRD 1984: Reinfed agriculture in perspective. Philippine Council for Agriculture and Resource Research and Development. Los Baños, Philippines

PENDLETON, J.W., JACKOBS, J.A., SLIFE, F.W., BATEMAN, H.P. 1957: Establishing legumes in corn. *Agron. J.* 49, 44-48

PHATAK, S.C. 1992: An integrated sustainable vegetable production system. *HortScience* 27(7), 738-741

RADKE, J.K., ANDREWS, R.W., JANKE, R.R., PETERS, S.E. 1988: Low-input cropping systems and efficiency of water and nitrogen use. Cropping strategies for efficient use of water and nitrogen. ASA Special Publication No. 51. ASA-CSSA-SSSA, Madison, USA

RADOSEVICH, S.R., WAGNER, R.G. 1986: Predicting effects of modified cropping systems: forestry examples. *HortScience* 21(3), 413-418

REDDY, K.C., SOFFES, A.R., PRINE, G.M. 1986A: Tropical legumes for green manure. I. Nitrogen production and the effects on succeeding crop yields. *Agron. J.* 78, 1-4

REDDY, K.C., SOFFES, A.R., PRINE, G.M. 1986B: Tropical legumes for green manure. II. Nematode populations and their effects on succeeding crop yields. *Agron. J.* 78, 5-10

RENNIE, R.J. 1984: Comparison of N balance and ^{15}N isotope dilution to quantify N^2 fixation in field-grown legumes. *Agron. J.* 76, 785-790

ROSSET, P.M., AMBROSE, R.J., POWER, A.G., HRUSKA, A.J. 1984: Overyielding in polycultures of tomato and bean in Costa Rica. *Trop. Agric. (Trinidad)* 61(3), 208-212

SARRANTONIO, M. 1992: Opportunities and challenges for the inclusion of soil-improving crops in vegetable production systems. *HortScience* 27(7), 754-758

SHENNAN, C. 1992: Cover crops, nitrogen cycling, and soil properties in semi-irrigated vegetable production systems. *HortScience* 27(7), 749-754

SITOMPUL, S.M., SYEKHFANI, M.S., VAN DER HEIDE, J. 1992: Yield of maize and soybean in a hedgerow intercropping system. *Agrivita* 15(1), 69-75

SUKMANA, S., SUWARDJO, H. 1991: Prospect of vegetative soil conservation measure for sustainable upland agriculture. *IARD Journal* 13(1 & 2), 1-7

SUR, H.S., MASTANA, P.S., HADDA, M.S. 1992: Effect of rates and modes of mulch application on runoff, sediment and nitrogen loss on cropped and uncropped fields. *Trop. Agric. (Trinidad)* 69(4), 319-322

UTOMO, W.H., SITOMPUL, S.M., VAN NOORDWIJK, M. 1992: Effects of leguminous cover crops on subsequent maize and soybean crops on an ultisol in Lampung. *Agrivita* 15(1), 44-53

VANDERMEER, J. 1981: The interference production principle: an ecological theory for agriculture. *Bioscience* 31, 361-364

VANDERMEER, J., AMBROSE, R., HANSEN, M., MCGUINESS, H., PHILLIPS, C., ROSSET, P., SCHULTZ, B. 1984: An ecologically-based approach to the design of intercrop agroecosystems: an intercropping system of soybeans and tomatoes in southern Michigan. *Ecological Modelling* 25, 121-150

VEEVERS, A., ZAFAR-YAB, M. 1980: Balanced designs for two-component competition experiments on a square lattice. *Euphytica* 29, 459-464

WAGGER, M.G., MENGEL, D.B. 1988: The role of nonleguminous cover crops in the efficient use of water and nitrogen. Cropping strategies for efficient use of water and nitrogen. ASA Special Publication No. 51. ASA-CSSA-SSSA, Madison, USA

WALLACE, R.W., BELLINDER, R.R. 1992: Alternative tillage and herbicide options for sucessful weed control in vegetables. *HortScience* 27(7), 745-749

WARE, L.M., JOHNSON, W.A. 1945: Effects of fertilizers, animal manures and green manures on the yield of vegetable crops on light garden soils. *Proc. Amer. Soc. Hort. Sci.* 46, 319-322

WILES, L.J., WILLIAM, R.D., CRABTREE, G.D., RADOSEVICH, S.R. 1989: Analyzing competition between a living mulch and a vegetable crop in an interplanting system. *J. Amer. Soc. Hort. Sci.* 114(6), 1029-1034

YIH, W.K. 1989: The effects of plant litter and inorganic fertilizer on crop-weed interactions in a temperate, rich-soil site. *Biological Agriculture and Horticulture* 6, 59-72