INTEGRATED CROPPING SYSTEMS: AN ANSWER TO ENVIRONMENTAL REGULATIONS IMPOSED ON NURSERY STOCK IN THE NETHERLANDS

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Abstract

Government regulations in the Netherlands are increasingly constraining and sometimes even banning conventional cultivation practices in nursery stock cropping systems. As a consequence, growers face problems concerning the use of manure, fertilisers and irrigation. In this study we analysed the production system and defined management options to improve input efficiency. Strategies based on results of small, preliminary experiments were then developed and tested in nursery stock production systems. Successful management tools included the use of alternative organic materials, such as black peat and compost of domestic and garden waste. The materials were applied after every harvest to maintain soil fertility. Split application of nitrogen and drip irrigation also proved to be successful. A prototype of an integrated nursery stock production system that meets the environmental regulations was developed for field-grown crops on sandy soils. Potential aspects for optimisation are pointed out and will be investigated in the near future.

1. Introduction

The approximately 10,000 ha under nursery stock in the Netherlands covers most soil types in the country and includes container nurseries and greenhouses (LEI and CBS, 1997). There is great diversity in crops, cropping systems and agronomic practice. High-valued crops like ornamental conifers and shrubs (2740 ha) are usually grown on sandy soils. Common treatments applied to planted rooted cuttings or liners include fertilisation, irrigation, and regular applications of chemicals to control weeds, pests and diseases. Growers have to take good care of soil fertility because of the limited nutrient content in sandy soils and because the soil is depleted by the bi-annual harvest of burlapped plants. Traditionally, large amounts of manure are applied to replenish the soil, which is estimated to be depleted by an average of 240 m^3 ha^{-1} every other year (≈ 8 tons of soil organic matter) for harvested conifers, to over 300 m^3 ha^{-1} (≈ 9 tons organic matter) for avenue trees lifted with root ball. Fertilisers are also applied frequently, especially during and after the second growing season. The combined application of manure and fertiliser often leads to excess fertilisation. Nutrient uptake by nursery stock ranges from 20 to 160 kg N ha^{-1} yr^{-1} (Oele, 1996) and 8 to 50 kg P_2O_5 ha^{-1} yr^{-1} whereas the average nitrogen load often exceeds 250 kg N ha^{-1} yr^{-1} and that of phosphate 100 kg P_2O_5 ha^{-1} yr^{-1}. In the Netherlands, the excess amount of nitrogen is usually leached out during the winter, by the excess precipitation . Additional losses occur due to irrigation after planting.

The excessive use of manure in the Netherlands has become a potential threat for groundwater pollution. Nitrate concentrations more than 2 to 3 times the standard of 50 mg NO_3^- l^{-1} are frequently encountered in surface water and shallow groundwater. Recent studies also indicate that 70% of the sandy soils are saturated with P_2O_5 (Breimer, 1994). The Dutch government has therefore developed a policy that aims to minimise the harmful effects of the large losses of minerals to the environment.

Until the early nineties, large volumes of groundwater were used for irrigation, causing the deep water tables to fall. To prevent a further lowering of the water table, irrigation of grassland and arable crops on sandy soils is currently limited and even prohibited during dry periods in the summer (Ministry of Agriculture, Nature Management and Fishery, 1999). Irrigation of field-grown nursery stock is not yet limited but will be in the near future. Field-grown nursery stock on sandy soils faces two major problems: (1) a potential loss of soil fertility due to the limited use of manure, and (2) a major decrease in growth and production, resulting from the irrigation restrictions.

It was against this background that a study was conducted with the aim of providing an overall framework for the development of cropping systems for nursery stock on sandy soils. Sustainable soil fertility, improved nutrient and water use efficiency, and acceptable environmental impacts within the socio-economic constraints of the nursery were the boundary conditions applied.

The approach in this research was to use a system analysis to identify options that maintain soil fertility and improve water and nutrient efficiency. These options were tested in field trials and the results were used to design prototypes (Vereijken, 1994) of integrated nursery stock production systems. The potential of these prototypes was investigated in semi-field scale experiments. Strategies for crop protection (weed and pest control), though essential in the development of integrated nursery stock production systems, will not be considered in this paper but should be incorporated later.

2. System description

2.1. Crop and soil

The system under consideration consists of two sub-systems: the crop and the soil (Fig. 1). This system is exposed to local meteorological conditions such as radiation, air temperature, humidity, wind speed, and precipitation, which affect crop photosynthesis and transpiration. Because these parameters are generally beyond the growers' control, they were considered to be 'disturbances'. On the other hand, soil ameliorants, fertilisation and irrigation were factors that the growers could control; we refer to these as 'controlled factors'.

Under the influence of controls and disturbances, the crop increases in weight (the desired process), develops and attains a certain quality (Fig. 1). Simultaneously, however, emission of nutrients occurs, and soil fertility (a long-term production factor) may decline as a result of insufficient nutrient supply and net removal of soil material.

Our goal was to define control strategies for this cropping system that achieve the multiple objectives, while respecting the prevailing constraints i.e. irrigation, nutrient emission, and weather. The second objective was to use system analysis to arrive at recommendations for the government and growers' organisations about the effectiveness of various options for legislation or regulation. We distinguished the following processes: soil fertility, movement of water and nutrients within the soil, growth and transpiration of the crop, and emission of nutrients to the lower soil horizons. The controlled factors should, as much as possible, (i) maintain optimal levels of water and nutrients near the roots and (ii) minimise leaching of minerals under the prevailing weather conditions.

2.2. Environmental regulations

The Dutch government's regulations are intended to reduce and, ultimately, prevent leaching of nutrients. The regulations constrain the 'application of manure' to specified maximum amounts of P_2O_5 (Table 1). It is prohibited to spread or apply manure on sandy soils from September through January. Between February and August, applications must be incorporated immediately, to minimise ammonia volatilisation. In addition, the government is introducing MINAS, the MINeral Accounting System (Ministry of Agriculture, Nature Management and Fisheries, 1999). MINAS registers all handling and applications of manure in the country. It works with levy-free surpluses. This means that nutrient input (registered) and output (estimated by crop removal and yield) are subtracted and a penalty must be paid when the surplus exceeds a certain threshold (Table 1).
Local governments impose a third constraint on growers: groundwater withdrawal for irrigation of grassland and arable crop production is prohibited in dry periods, to prevent deep water tables from falling in the summer. Regulations have been prepared for horticulture and will be implemented in the near future. A certain amount of irrigation, however, remains necessary to maintain optimal crop production.

2.3. Options to improve system performance

We studied the effect of restrictions on the use of inputs to produce marketable plants. Options that comply with current environmental regulations and improve system performance include:
1. Use of alternative soil ameliorants instead of manure to prevent loss of soil fertility (Fig. 1). These materials must have a high organic matter content, low nutrient content, and low decomposition rates.
2 Use of split applications of nitrogen to optimise plant-available nitrogen. The split application system takes into account the actual available soil nitrogen and crop demand, to determine application rates that provide optimal nitrogen levels near the roots.
3. Use of drip irrigation to prevent leaching to groundwater. Drip irrigation guidelines are based on soil and crop characteristics such as the actual soil water content in combination with on-site weather data.

These options were investigated in small field trials and laboratory trials (Oele, 1993; Aendekerk, 1994; Oele, 1994) and the results were used to develop an integrated nursery production system.

3. Prototype integrated nursery stock production system

The prototype nursery based on integrated production principles for field grown ornamental shrubs and conifers was established in 1991 (Dolmans, 1992) on a sandy siliceous mesic udic Plaggept (Soil Survey Staff, 1975) in Horst (lat. 51°25'N, long. 06°05'E), the Netherlands.

A crop rotation with 7 different groups of crops was established on the field of 0.8 ha (Table 2). Alternative soil ameliorants were compared and the applications of nitrogen were split. The effects of these strategies were evaluated intensively on main plot number VIII, following the crop rotation of *Tagetes patula* (1991), *Mahonia aquifolium* 'Apollo' (1992-1993; harvested with root ball) and *Thuja occidentalis* 'Brabant' (1994-1995; harvested with root ball). Drip irrigation was investigated on main plot IV in *Thuja plicata* 'Atrovirens' (1997-1998).

3.1. Alternative soil ameliorants

The strategy to maintain soil fertility was the application of black peat and compost. The materials were applied before the crop was planted in the spring (Table 3). Changes in soil organic matter content, total C (Nelson and Soomers, 1982) and N (Bremmer and Mulvaney, 1982), and water-extractable P_2O_5 (Pw, Sissingh, 1971) and K_2O (extraction with HCl), were monitored for 5 years. The soil on which the prototype was established had good fertility at the start of the experiment in 1991. Prior to the experiment the research site had been conventionally cultivated for many years.

3.2. Split application system for nitrogen

To assess the amount of nitrogen necessary in the split application (May and end of June) both the average nitrogen uptake by crops (Oele, 1996) and the actual nitrogen content of the soils was determined. In the split application system, the mineral soil nitrogen content was measured twice during the growing season. The soil mineral nitrogen content was subsequently subtracted from the standard application rate to obtain the actual application rate.

3.3. Drip irrigation and fertigation

In field trials, the effectiveness of drip irrigation was compared with non-irrigated treatments. The combination of fertilisation and irrigation, fertigation, was studied. It proved to be successful for certain crops (Pronk and Ravesloot, 1998). However, not every crop responded well to irrigation or fertigation. Problems such as root rot limited the utility of this technique in conifers like *Chamaecyparis* and *Taxus*.

The usefulness of drip irrigation was evaluated by dividing the experimental field into two areas; one area was drip irrigated and the other was sprinkle irrigated, following the standard irrigation practices. A fixed application rate of 0.5 litre per plant per day was used to drip irrigate first-year liners of *Thuja plicata* 'Atrovirens'. The irrigation started in the third week of May and continued for 90 days. No additional nitrogen fertiliser was needed because the well water used for irrigation contained almost 200 mg NO_3^- l^{-1}. To evaluate growth response the height of 25 plants per area was measured on the planting date and monthly during the growing season.

4. Results

4.1. Alternative soil ameliorants

The amount of organic matter removed at the harvest, approx. 8 tons ha^{-1}, was replaced completely by adding compost and black peat. As a result of these additions, the soil organic matter content, and also the total C and N content of the topsoil (0 to 30 cm) remained constant or increased slightly (Table 4). The stability of compost and black peat, determined as the average decomposition rate, was higher than that of manure (data not shown). This means that more organic matter was added in the prototype than would have been added if the maximum permitted amount of manure had been applied.

Despite the low P_2O_5 content of compost (6 kg ton^{-1}) and black peat (1 kg ton^{-1}), the average P_2O_5 content of the soil was still high after 5 years of repeated applications of both materials (Table 4). Potassium levels remained within the standard range for optimal crop production, i.e. between 10 and 19 mg K_2O per 100 g soil.

4.2. Spit application system for nitrogen

From the small-scale experiments, we concluded that the proposed nitrogen application rates based on the split application system in combination with plant uptake, were lower than the standard application rates in the case of a single application at the start of the growing season.

The measured mineral soil N content was 62 to 196 kg N ha^{-1} in the first year and 8 to 244 kg N ha^{-1} in the second year (Table 5). Only in the second growing season were 50 kg N ha^{-1} of fertiliser applications needed to maintain levels optimal for crop production. In the split application system, application rates were decreased compared with the conventional system and total nitrogen load fell considerably. A possible explanation for the high mineral N content of the soil and the boosting effect of small nitrogen applications may lie in the history of the field. The large volumes of manure (> 50 tons ha^{-1}, applying more then 345 kg N and 190 kg P_2O_5 ha^{-1}) applied in the past raised the levels of easily degradable organic matter content. We expect this effect to decrease with time, although no indications of this have so far been found.

4.3. Drip irrigation and fertigation

In 1997 the drip-irrigated plants were taller than sprinkle-irrigated plants (Table 6). However, no differences were found in plant height at the end of the second growing season. Note that in 1998, however, the precipitation at the research site during the summer was 96% higher during May to August than the average during that period for the preceding 5 years (1993-1997). That year, irrigation was not necessary for optimal crop production.

5. Discussion

The proposed strategies to improve system performance were implemented successfully in the integrated nursery stock system. Although the system remained within the boundary conditions, some aspects need more attention and some may become further constraining if government regulations change.

Soil fertility was maintained by the proposed strategy, but the input-output balance for soil was still not at equilibrium. Over time, there is a net removal of 200 m^3 soil material ha^{-1} at every harvest. Growers export their valuable plough layer and may end up with the nutrient-poor parent material (aeolian sand). The A_h horizon (3% OM) ranged from 55 to 95 cm at the location for nursery research in the seventies. A recent field survey, however, indicated that the thickness of the A_h horizon had decreased to 40 to 65 cm. Studies on alternative packaging to prevent drying out of avenue trees have had good results (Horticultural Development Council, 1994). This option might be appropriate for conifers harvested with root ball too.

The soil sampling and the split application system used in our study enabled us to reduce nitrogen applications – and even to dispense with them several times. However, when many different crops are grown, sampling can be expensive. An alternative for sampling could be to use models that predict the actual N status of the soil. A few soil samples for mineral nitrogen would suffice to update the model. The estimated nitrogen mineralisation for the next few weeks could be taken into account when actual fertiliser applications are determined.

The superior plant height of *Thuja plicata* 'Atrovirens' plants in drip-irrigated liners was not achieved in the second year because of the abnormally high precipitation rates in the summer. Fixed daily rates of irrigation may give rise to leaching at high rainfall, whereas crop growth may require larger applications when temperature and irradiation are high and precipitation is low or absent. One of the methods available to predict irrigation needs for various crops is to use one-dimensional soil water balance calculations, based on crop evapotranspiration rates (Belmans et al., 1983) and on-site weather data. This entails determining the potential evapotranspiration rate for each crop in different developmental stages, under Penman conditions (Doorenbos and Pruitt, 1977). This approach is not very appropriate for nursery stock with its great diversity of crops, cropping systems and agronomic practices. Furthermore, one-dimensional soil water movement models are not suitable because the Richards equation (Richards, 1931) should be used in variably saturated, heterogeneous, isotropic, rigid, isothermal porous media (Heinen, 1997).

One solution to the problem of estimating irrigation or fertigation requirements and leaching of nutrients to the groundwater in nursery stock could be to use models of potential crop growth (Goudriaan and van Laar, 1994). These models describe the sub-system CROP and the interaction with the sub-system SOIL: growth, nutrient uptake, evapotranspiration rates (under the local meteorological conditions), and reduced photosynthesis at increased soil water tension (Fig. 1). In combination with two-dimensional models for soil water balance calculations, (sub-system SOIL), they provide a powerful tool to improve the system for field-grown nursery stock.

The strategies developed in our study will improve the efficiency of various inputs and enable growers to run a successful production system. At present, an integrated approach is a successful strategy for nursery production that meets all boundary conditions without production losses. However, irrigation and fertigation practices need more research in the near future, because in specific circumstances environmental regulations may not be met.

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Tables

1. Phosphate input standards and levy-free surpluses of P_2O_5 and N (kg ha^{-1} yr^{-1})

	1998	2000	2002	2005	2008/'10
Input standards (P_2O_5 in kg ha^{-1})					
Grassland	120	85	80	80	80
Arable land	100	85	80	80	80
Levy-free surpluses (P_2O_5 in kg ha^{-1})					
Grassland	40	35	30	25	20
Arable land	40	35	30	25	20
Levy-free surpluses (N in kg ha^{-1})					
Grassland	300	275	250	200	180
Arable land	175	150	125	110	100

2. Crop rotation scheme for the integrated nursery stock production system of ornamental shrubs and conifers (after Dolmans, 1992)

Main plot	Year							
	'91	'92	'93	'94	'95	'96	'97	'98
I	A	G	C	C	F	F	G	A
II	D	D	G	B	B	E	E	G
III	C	C	F	F	G	A	A	D
IV	G	A	A	D	D	G	E	E
V	G	E	E	G	A	A	D	D
VI	F	F	G	A	A	D	D	G
VII	B	B	D	D	G	C	C	F
VIII	G	B	B	E	E	G	C	C

A: *Rosacea*: cultivars of *Rosa, Potentilla, Malus, Prunus, Amelancier*
B: evergreen shrubs: cultivars of *Mahonia, Ilex, Viburnum*
C: deciduous shrubs: cultivars of *Callicarpa, Magnolia, Cornus*
D: conifers susceptible to *Phytophthora cinnamomi*: cultivars of *Chamaecyparis, Taxus*
E: conifers (*Cupressaceae*): cultivars of *Juniperus, Thuja*
F: conifers (*Pinaceae*): cultivars of *Abies, Picea, Pinus*
G: *Tagetes*

3. Application of alternative soil ameliorants in the prototype integrated nursery stock production system in Horst

	1992[1]	1994
Material	black peat +compost	Black peat +compost
Amount (tons ha^{-1})	7 + 10	8 +12
Organic matter application (tons ha^{-1})	6 + 3	7.4 +3.6

1 two years

4. Changes in soil characteristics (0-30 cm) in the prototype on integrated nursery stock production system in Horst

	1991	1992	1993	1994	1995
Crop	*Tagetes* patula	*Mahonia aquifolium* 'Apollo' 1[st] year	2[nd] year	*Thuja occidentalis* 'Brabant' 1[st] year	2[nd] year
O.M. (%)	2.7	3.0	2.8	2.8	3.1
pH	5.5	5.6	5.7	5.4	5.5
Pw[1]	96	131	122	119	102
K[2]	12	15	13	12	13
N-total[3]	-[4]	0.093	-	-	0.111
C-total[3]	-	1.31	-	-	1.86

[1] Pw in mg P_2O_5 per litre air-dried soil
[2] K in mg K_2O per 100 g soil
[3] N in g per 100 g soil, C in g per 100 g soil

5. Split application system for nitrogen fertiliser applications in the integrated nursery stock production system in Horst

	1991		1992		1993		1994		1995	
	Tagetes patula		*Mahonia aquifolium* 'Apollo'				*Thuja occidentalis* 'Brabant'			
	May	June	May	June	May	June	May	June	May	June
			1[st] year		2[nd] year		1[st] year		2[nd] year	
Standard application rate (kg N ha^{-1})		100	75		100		75		100	
Split application rate (kg N ha^{-1})	-[1]	100	50	50	75	50	50	50	75	50
Mineral N (0-30 cm, kg N ha^{-1})	-	131	62	196	18	244	64	71	8	109
Actual application rate (kg N ha^{-1})	-	0	0	0	50	0	0	0	50	0
Savings [2] (kg N ha^{-1})		100	75		50		75		50	

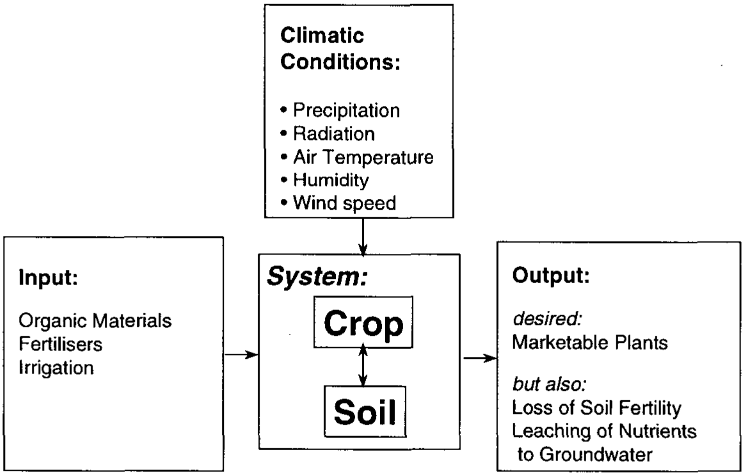
[1] *Tagetes patula* was sown in June. No soil sample was taken in May.
[2] Savings are calculated as standard application minus actual application

6. Plant height of drip-irrigated and sprinkle-irrigated *Thuja plicata* 'Atrovirens'

	Irrigation	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Dec
1997	Drip	-[1]	-	32[2]	35	44	53	62	69	72	72
	Sprinkle	-	-	32[2]	34	42	50	60	64	66	66
1998	Drip	72	73	75	85	86	96	105	116	117	
	Sprinkle	66	67	69	80	83	94	100	109	111	

[1] Before planting

Figures



1. System for field grown nursery stock