Management approaches in organic potato and tomato production

Interactive impacts of agronomical measures on plant nutrition, plant health and yield

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"I want to stand as close to the edge as

I can without going over.

Out on the edge you see all the kinds of things

you can't see from the center."

- Kurt Vonnegut

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Summary

This presented thesis considered three different system approach topics to ensure yield and plant health in organically grown potatoes and tomatoes. Based on several field trials Chapter 2 describes challenges to organic potato farming in disease and nutrient management focussing in detail on the interactions between late blight (*Phytophthora infestans*), and soil nitrogen supply on yield-loss relationships in organic farming. Chapter 3 describes the effect of some selected organic fertilisers and biostimulant products on nitrogen-mineralisation and efficiency, yield and diseases in organic potato and tomato trials. Chapter 4 focuses on the effect of suppressive composts on the saprophytic pathogen *Rhizoctonia solani* in organic potato systems.

In chapter 2 the state of the art of organic potato management with respect to disease and nutrient management is summarised. In a second part, the interactive effects of N-availability in the soil, climatic conditions and late blight were studied in the presence and absence of copper fungicides from 2002-2004 for the mid-early main-crop potato cultivar Nicola.

- From the experimental work it became clear that copper fungicides in most cases slow down epidemics somewhat adding an average of 3 days to the growth duration. However, only 30 % of the variation in yield could be attributed to disease reductions. A multiple regression model (R^2Max) additionally including the factors (i) disease reduction, (ii) growth duration, (iii) temperature sum from planting until 60 % disease severity was reached, and (iv) soil mineral N contents at 10 days after emergence could explain 75% of the observed variation in yield. However, the model failed when N-supply was with 280 kg N ha^{-1} extremely high.

The implications of the results on the management of organic potatoes with respect to cultivar choice, nutrient and disease management are discussed. In conclusion, several points emerge from the presented results:

- In organic farming, yields are foremost limited by nutrient availability in spring and early summer.

- The effects of late blight on yields in organic farming may often be overestimated and cannot be deducted from results in conventional farming because of the strong interaction with nutrient status.

- As important as cultivar resistance or even more important is the early development, the bulking behaviour and the ability of a cultivar to make use of organic nutrients efficiently.

- Under conditions of central Germany the use of copper reduced late blight significantly in almost all cases (15-30 %). However, the reductions in disease through copper application did not result in significant yield increases (+0 – 10 %). With reduced disease pressure and low N-supply there were almost no effects of copper fungicides on yield.

Chapter 3 describes the effect of some selected organic fertiliser and biostimulant products on nitrogen efficiency, yield and diseases in organic potato and tomato trials. The slow release fertilisers Biofeed Basis (BFB, AgroBio Products, Wageningen, NL) a complex mix of plant derived material and BioIlsa 12,5 Export (BI 12, ILSA-Group, Agriziano, Italy) an organic nitrogen fertiliser manufactured through physical hydrolysis of leather shavings of bovine hides were used. In addition two biostimulants or plant strengthener products BioFeed Quality (BFQ) (AgroBio Products, Wageningen; NL), an aqueous multi-compound extract from 2 types of seaweed added with 2 % dried thyme (*Thymus vulgaris*) and reinforced with humic and fulvic acids and AUSMA (Biolat, Salaspils, Latvia) an aqueous extract from pine and spruce needles. All products are permitted in organic farming according to the EC – regulation 2092/91.

- All tested fertilisers supplied considerable amounts of soil N-min during the main uptake phases of both crops resulting in adequate N uptake dynamics in potatoes compared to horn meal which is routinely used as fertiliser in organic farming. In potatoes, across fertilisation levels, 34-58 % of the N-input supplied by the fertilisers (compared to crop uptake without N-input) was taken up by haulms and tubers by mid July (95 days after planting) when applied directly into the potato row.

- In the trials the fertiliser treatments showed similar growth dynamics on potatoes and tomatoes and resulted in almost similar or higher yields as compared with the control plots treated with horn-meal. Potato yield increases per kg applied nitrogen varied among cultivars and N-input levels. However, both BFB and BI 12 achieved between 9-20 kg more yield per kg N-input compared to horn meal. At moderate N –supply levels of 40 and 75 kg N ha^{-1}

the efficiency of the tested fertilisers ranged between 90 and 159 kg yield kg^{-1} N–input.

- Combined treatments of the fertiliser BFB and the biostimulants AUSMA and BFQ were most effective in tomatoes by increasing the marketable yield significantly. On one hand the biostimulants significantly increased the share of healthy fruits and on the other hand the number of fruits, particularly in the combination BFB + BFQ. Additionally BFQ significantly increased potato yields (+6 %) in one out of two years.
- The significantly higher late blight reduction in leaf inoculation tests and the reduction in number of infected fruits in the field trials after the treatment with BFQ and AUSMA suggest that the products induce some plant resistance mechanisms against the pathogen. However, no effects of the biostimulants on potato late blight could be observed.
- Effects on black scurf (*R. solani*) severity were reduced significantly in 2005 by 38 % when sprayed with the biostimulant BFQ. Plant derived BFB reduced infestation with common scab (*S. scabies*) (-25 %) compared to the animal derived fertilisers.
- In conclusion, both fertilisers BF Basis and BioIlsa 12,5 Export and the biostimulants BFQ and AUSMA resulted in some positive effects on plant growth and plant health status, especially the combination of well adapted liquid and solid products can have promising effects on crop performance.

In the present study 5t ha^{-1} DM of a yard and bio waste (60/40) compost produced in a 5 month lasting composting process and a 15 month old 100 % yard waste compost were used to assess the effects on potato infection with *R. solani* when applying composts within the limits allowed. Strip and broadcast applications were compared to test, if compost effects can be optimised through targeted application at the seed tuber area.

- Across the differences in initial seed tuber infestation (trial 2) and 12 cultivars (trial 3) 5t DM ha^{-1} of high quality composts applied as strip in the plant row reduced the infestation of harvested potatoes with black scurf, tuber malformations and dry core tubers by 20 to 84 %, 20 to 49 % and 38 to 54 %, respectively while marketable yields were increased by 5 to 25 %. Yield increases were due to lower tuber sorting

cull due to the reduced amount of tubers with malformations, dry core and black scurf infestation of more than 15 %, as well as to the higher tuber number per plant than in the control.

- When same amounts of compost were applied broadcast (trial 1) disease suppression was much less effective particularly in no reduction of tuber malformations.
- The rate of initial black scurf infection of the seed tubers also affected tuber number, health and quality significantly. Compared to healthy seed tubers initial black scurf sclerotia infestation of 2-5 and >10 % of tuber surface lead in untreated plots to a decrease in marketable yields by 14-19 and 44-66 %, a increase of black scurf severity by 8-40 and 34-86 % and also increased amount of malformed and dry core tubers by 32-57 and 109-214 %.

Zusammenfassung

Diese Arbeit betrachtete verschiedene Systemsansätze bezüglich der Sicherung von Ertrag und Pflanzengesundheit bei nach Richtlinien des Ökolandbaus angebauten Kartoffeln und Tomaten. Kapitel 2 beschreibt basierend auf mehreren Feldversuchen Herausforderungen im ökologischen Kartoffelanbau, unter besonderer Berücksichtigung der Wechselwirkung zwischen Krautfäulebefall und Boden N-Angebot in Bezug auf die durch *P. infestans* bedingten Ertrags-Verlust-Beziehungen.

Kapitel 3 beschreibt den Effekt ausgewählter kommerzieller organischen Düngemittel und Biostimulantien bzw. Pflanzenstärkungsmittel auf N Mineralisation, Ertrag und Pflanzengesundheit in Versuchen mit Tomaten und Kartoffeln unter ökologischen Anbaubedingungen. Kapitel 4 befasst sich dem Einsatz von suppressiven Komposten zur Verminderung des Befalls durch den saprophytischen Krankheitserreger *Rhizoctonia solani.*

Die Situation im ökologischen Kartoffelanbau wird hinsichtlich Krautfäulebefall und N Versorgung in Kapitel 2 zusammengefasst. Der zweite Teil des Kapitels beschreibt anhand von Feldversuchen in den Jahren 2002-2004 die interaktiven Effekte von Boden N Angebot, klimatischen Bedingungen und Krautfäulebefall mit und ohne Kupferschutz bei der mittelfrühen Sorte Nicola.

- Aus den Versuchen ging hervor, dass der Einsatz von Kupferfungiziden in den meisten Fällen den Krautfäuleverlauf verlangsamte und dadurch die Wachstumsphase um durchschnittlich drei Tage verlängerte. Allerdings waren nur 30 % der Ertragsvariationen durch die Reduzierung des Befalls erklärbar. Die Einbeziehung von der Faktoren Befallsreduktion, Wachstumsdauer und Temperatursumme von der Pflanzung bis zu einem Befall von 60 %, sowie des Boden N-min Gehaltes 10 Tage nach Bestandsaufgang in einem multiplen Regressions-Modell (R^2Max) erklärten 75 % der Ertragsschwankungen. Bei einem extrem hohen nicht praxisüblichen N-min Gehalt von 280 kg ha^{-1} war dieses Modell allerdings nicht mehr anwendbar, um mögliche Ertragseinflüsse darzustellen.

Die Einbeziehung der Ergebnisse ins Anbaumanagement wurde unter Berücksichtigung von Sortenwahl, Nährstoffangebot und Befall diskutiert. Aus den Ergebnissen ergaben sich folgende Schlüsse:

- Im ökologischen Kartoffelanbau sind die Erträge hauptsächlich durch ein geringes N- Angebot im Frühjahr und Frühsommer limitiert
- Der Einfluss der Krautfäule auf Ertrag wird oftmals für den ökologischen Landbau überschätzt und kann aufgrund der Interaktion zwischen N-Angebot und Befall nicht mit den Ertrags-/Verlustbeziehungen aus konventioneller Bewirtschaftung berechnet werden.
- Noch mehr als die Resistenzeigenschaften sind frühe Knollenentwicklung sowie eine effiziente Nutzung des Nährstoffangebotes einer Sorte von Bedeutung.
- Der Einsatz von Kupferfungiziden unter Bedingungen in Nordhessen und Südniedersachsen reduzierte zwar die Befallsschwere um ca. 15-30 %, allerdings konnten keine statistisch signifikanten Ertragssteigerungen festgestellt werden (+0 bis +10 %). Bei milden Befallsverlauf und niedrigem Stickstoffangebot ergab sich nahezu kein Ertragseffekt mit Kupferfungiziden .

Kapitel 3 beschreibt die Effekte von ausgewählten kommerziellen organischen Düngemitteln und Pflanzenstärkungsmitteln in Feldversuchen auf Kartoffeln und Tomaten hinsichtlich Stickstoffeffizienz, Ertrag und Pflanzengesundheit. Die getesteten organischen Düngemittel waren Biofeed Basis (AgroBio Products, Wageningen; NL), ein Mix aus pflanzlichen Rohstoffen angereichert mit Rohphosphat, Kaliumsulfat und Kalk sowie Bio Ilsa 12,5 Export (ILSA-Group, Agriziano, Italien) ein durch physikalische Hydrolisierung von Rinderhaaren produzierter organischer N Dünger. Darüber hinaus wurden die Pflanzenstärkungsmittel BioFeed Quality (BFQ) (AgroBio Products, Wageningen; NL), eine wässerige Extraktion aus zwei Algentypen und 2 % getrocknetem Thymian (*Thymus vulgaris*) angereichert mit Humin und Fulvinsäuren sowie AUSMA (Biolat, Salaspils, Lettland) eine wässerige Extraktion aus Kiefern- und Fichtennadeln getestet. Alle Produkte sind nach den EU Richtlinien 2092/91 für den Einsatz im Ökologischen Landbau zugelassen.

- Alle getesteten Düngemittel stellten in den Hauptaufnahmephasen beider Kulturen vergleichbare Mengen an Stickstoff wie bei Hornmehl Referenzdüngung bereit. Im Mittel der N-Düngestufen (bei Reihendüngung) konnten 95 Tage (Mitte Juli) nach Pflanzung eine N-Aufnahme von 34-58 % des Stickstoffs aus den Düngern (verglichen mit ungedüngter Variante) in Kraut und Knollen der Kartoffeln nachgewiesen werden.

- In den Versuchen zeigten die getesteten Düngemittel bei Tomaten und Kartoffeln vergleichbare Wachstumsverläufe und mindestens gleiche oder höhere Erträge als in den mit Hornmehl gedüngten Kontrollbehandlungen. Der Mehrertrag bei Kartoffeln pro gedüngtes kg N unterschied sich hinsichtlich der Sorten und des N Düngeniveaus. Allerdings zeigten verglichen mit Hornmehl sowohl BFB als auch BI 12 ein um 9-20 kg gesteigerten Ertrag pro kg N- Düngung. Bei moderater Düngung von 40 und 75 kg N ha^{-1} lag die N- Effizienz zwischen 90 and 159 kg Ertrag kg^{-1} N – Zufuhr.
- Die kombinierten Behandlungen des Düngers BFB jeweilig mit den Pflanzenstärkungsmitteln AUSMA und BFQ erbrachten eine signifikante Steigerung des marktfähigen Tomatenertrages. Zum einen wurde die Anzahl mit Bräunfäule befallener Früchte verringert und zum anderen ein höherer Fruchtansatz besonders in der Kombination BFB + BFQ erzielt. Die Kartoffelerträge wurden zumindest in einem von zwei Jahre durch die Behandlung mit BFQ signifikant erhöht (+6 %), während im zweiten Versuchsjahr keine Ertragseffekte beobachtet werden konnten.
- Die signifikant höheren Reduktionen der Krautfäule in Blatttests mit Tomaten im Labor und in der Anzahl befallener Früchte in den Feldversuchen nach der Behandlung mit AUSMA und BFQ deuten auf Merkmale induzierter Resistenz hin. Allerdings konnte in den Kartoffelversuchen kein Effekt auf die Krautfäuleepidemie festgestellt werden.
- Der Sklerotienbesatz (*R. solani*) an geernteten Kartoffeln wurde durch die Behandlung mit BFQ signifikant reduziert(- 38 %). Bei einer Düngung mit dem aus pflanzlichen Rohstoffen bestehenden BFB war der Schorfbesatz um 25 % niedriger als bei Düngung mit BI 12 und Hornmehl, welche tierischer Herkunft sind.
- Insgesamt zeigten die Dünger BF Basis und BioIlsa 12,5 Export und die Pflanzenstärkungsmittel BF Quality und AUSMA insbesondere in der kombinierten Behandlung vielversprechende positive Effekte auf Pflanzenwachstum und –gesundheit.

In dieser Arbeit wurde außerdem der Effekt von Grüngut- und Bioabfallkompost (60/40) nach fünfmonatiger Kompostierungsphase sowie ein 15 Monate kompostierter 100 % iger Grüngutkompost in der zugelassenen Menge von 5 t ha^{-1} DM auf den Befall mit *R. solani* untersucht. Streifenablage und breitflächige Ausbringung wurden verglichen, um zu testen, ob eine Ablage in direkter Umgebung der Mutterknolle eine Befalls unterdrückende Wirkung steigert.

- Im Mittel über den unterschiedlich starken Ausgangsbefalls der Pflanzknollen (Versuch 2) und von 12 Sorten (Versuch 3) reduzierte die Streifenablage von 5 t DM ha^{-1} hoch qualitativer Komposte die *R. solani* Schadbilder Pockenbesatz um 20 bis 84 %, Knollendeformationen um 20 bis 49 % und die lokale Trockenfäule um 38 bis 54 %. Der marktfähige Ertrag wurde durch den geringeren Sortierabfall aufgrund geringerer Anzahl an Knollendeformationen, lokaler Trockenfäule, Knollen mit einem Pockenbesatz von über 15 % sowie durch die erhöhte Anzahl von Knollen pro Pflanze um 5 bis 25 % gesteigert.
- Die Unterdrückung des Befalls des Kompostes war deutlich geringer, wenn die gleiche Menge and Kompost breitflächig ausgebracht wurde (Versuch 1) anstelle der Streifenablage. Insbesondere zeigte sich dies deutlich bei den Knollendeformationen, die im Gegensatz zur Streifenablage mit breitflächiger Ausbringung nicht reduziert wurden.
- Der Ausgangsbefall des Pflanzgutes beeinflusste die Knollenanzahl, -gesundheit und –qualität signifikant. Verglichen zu gesundem Pflanzgut führte ein Ausgangsbefall von 2-5 and >10 % zu 14-19 und 44-66 % geringerem marktfähigen Ertrag sowie zu einem erhöhten Pockenbesatz von 8-40 und 34-86 % und eine um 32-57 und 109-214 % erhöhte Anzahl an Deformationen und lokaler Trockenfäule.

1. General introduction

Organic farming relies on a long-term integrated approach rather than the more short-term targeted solutions common in conventional agriculture. For organic farmers it is important to recognise that the relationships that exist between different system components are complex and thus the sustainability of the system is dependent upon the functioning of a whole integrated and inter-related system (Atkinson & Watson 2000). For this reason, soil fertility is central to organic farming and includes not only the supply of nutrients to plants but also soil structure and very important soil health to enable plants to grow.

The most important element in building up a sustainable organic cropping system is the rotation design for nutrient cycling and conservation and weed, pest and disease control (Lampkin 1990, Heß 1989 & 1995, Stockdale et al. 2001, Watson et al. 2002). Crop rotations, including a mixture of leguminous fertility building and cash crops, are the main mechanism for nutrient supply within organic systems. Legume based leys are the principle fertility building crops. However, they can differ extremely in their N_2 – fixation, depending on growing conditions, legume species and cultivar, proportion of legume in the ley, management, and the age of the ley. N accumulation according to several studies ranged between 20and 500 kg N ha^{-1} (Spiertz & Sibma 1986, Heß 1989, Kristensen et al.1995, Schmidt et al 1999). This nitrogen is subsequently made available after incorporation by mineralization. In a long term trial in comparing different agricultural systems in Switzerland soil microbial activity was enhanced and soil organic matter and organic N increased in the organic systems (Fließbach & Mäder 2000).

Further nutrient sources are organic fertilisers such as solid and liquid animal manures, green manures and composts. With the exception of liquid manure these fertilisers are usually slow release and highly dependent on the soil moisture and temperature for mineralization processes that make the nutrients available to the plants (van Delden 2001; Haase et al. 2007, Gruber et al. 2003). In high value vegetable crops, more expensive fertilisers that supply nutrients more rapidly such as hair meal pellets, molasses, horn and legume meals etc. are also used (Müller & Von Fragstein, 2005; Raupp, 2005).

Disease management must also be considered in a systemic approach. Crop protection in organic farming is generally not directed at controlling particular pathogens or pests but at management of the environment so that plants are able to withstand potential attacks. Resistant cultivars adapted to local conditions are in demand among organic farmers. The most important practices contributing to disease prevention and control are long, balanced rotations, organic amendments and reduced tillage, all geared towards maintenance of the soil organic matter content and fertility (Watson et al. 2002,. Van Bruggen & Termorshuizen 2003, Bailey. &. Lazarovits 2003, Möller & Reents 2007) Soil borne pathogens are influenced by rotation length, with reduced disease levels associated with longer gaps between susceptible crops (Clark et al. 1998). Increased soil microbial activity may contribute to the control of soil borne diseases, leading to increased competition, parasitism and predation in the rhizosphere (Workneh & van Bruggen 1994; Knudsen et al. 1995, Fließbach & Mäder 2000). Nevertheless, managing soil fertility and diseases is complex. For example, the incorporation of green manures and plant residues has positive effects on the N management. However, raw organic matter also favours plant pathogens with a saprophytic phase such as *Rhizoctonia solani* which can multiply in plant debris (Weinhold 1977).

In addition to fertility management, organic farmers can make use of products containing biological control agents and natural toxic compounds in plant extracts or products known as biostimulants or plant strengtheners which should enable plants to stimulate growth, induce plant resistance or stimulate soil life. Sulphur and copper fungicides are mainly used in pomiculture, vineyards, hops, tomato and potato production to control downy mildews and late blight.

The aim of the present thesis is to evaluate different agronomic measures in managing selected diseases and optimising nutrient management in organic potato and tomato production. The thesis is divided into five chapters. The following chapters 2-4 comprise three manuscripts which will be or are submitted to international peer-reviewed journals. Chapter 2 describes challenges to organic potato farming in disease and nutrient management focussing in detail on the interactive effects of late blight, nutrient availability, and yield losses in organic farming. These were determined in a series of field trials from 2002-2004 (published in Potato Research 49(1)). Chapter 3 describes the effect of some selected organic fertiliser and biostimulant products on nitrogen efficiency, yield and diseases in organic potato and tomato trials. Chapter 4 focuses on the effect of suppressive composts on the saprophytic pathogen *Rhizoctonia solani* in organic potato systems. The final chapter is a concluding discussion about the implication of the results on soil fertility management in organic farming.

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2. Challenges to organic potato farming: Disease and nutrient management

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Abstract

For organic potato producers the two main challenges are disease and nutrient management. Both factors are limited by regulations that on the one hand prohibit the use of chemical fertilisers, especially nitrogen and, on the other hand, most synthetic pesticides.

Late blight, caused by *Phytophthtora infestans* is commonly thought to be the factor most limiting yield, however, because there is no really effective fungicide available to control late blight, there are virtually no yield loss data available for organic farming conditions.

In this paper the state of the art of organic potato management with respect to disease and nutrient management is summarised. In a second part, the interactive effects of N-availability in the soil, climatic conditions and late blight were studied in the presence and absence of copper fungicides from 2002-2004 for the mid-early main-crop potato cultivar Nicola.

From the experimental work it became clear that copper fungicides in most cases do slow down epidemics somewhat adding an average of 3 days to the growth duration. However, only 30 % of the variation in yield could be attributed to disease reductions. A model including disease reduction, growth duration and temperature sum from planting until 60 % disease severity was reached, and soil mineral N contents at 10 days after emergence could explain 75 % of the observed variation in yield. However, the model failed when N-supply was extremely high.

The implications of the results on the management of organic potatoes with respect to cultivar choice, nutrient and disease management are discussed.

In conclusion, several points emerge from the presented results: In organic farming, yields of potatoes are foremost limited by nutrient availability in spring and early summer. The effects of late blight on yields may often be overestimated and cannot be deducted from results in conventional farming because of the strong interaction with nutrient status. Resistance clearly remains the most important strategy against late blight in organic potato production. However, as important or even more important as resistance is the early development and bulking behaviour and the ability of a cultivar to make use of organic nutrients efficiently. In the absence of efficient organic pesticides it is possible to reduce blight pressure to a certain extent by arranging the crop in small narrow fields perpendicular to the main wind direction neighboured either by non-hosts or completely resistant potatoes.

Keywords: Organic farming, Plant nutrition, *Phytophthora infestans*, yield loss, copper fungicides

2.1. Introduction

For organic potato producers the two main challenges are disease and nutrient management. Both factors are limited by regulations that on the one hand prohibit the use of chemical fertilisers, especially nitrogen and, on the other hand, synthetic pesticides (EU-regulation 2092/91).

Plant nutrition in organic farming therefore relies on carefully designed rotations including ideally 25 % or more legumes in the rotation and the addition of organic fertilisers such as solid and liquid animal manures, green manures, and composts. With the exception of liquid manure these fertilisers are usually slow release and highly dependent on the soil moisture and temperature for mineralization processes that make the nutrients available to the plants (van Delden, 2001; Haase et al. 2005; Gruber et al. 2003). In high value vegetable crops, more expensive fertilisers that supply nutrients more rapidly such as hair meal pellets, molasses, horn and legume meals etc. are also used (Müller and Fragstein und Niemsdorff, 2005; Raupp, 2005).

In potato production, rotations, cover and green manure crops and animal manure are typically used to manage nutrients. Unfortunately, there are strong interactions between the type and timing of nutrient application and several pests and diseases, especially wire worms and black scurf (caused by *Rhizoctonia solani*). While wire worms (*Agriotes* spec. among others) are often a problem if the potatoes follow in the rotation after several years of pasture or grass-clover (Schepl et al.,2003; Paffrath, 2002). *R. solani* is favoured by high amounts of raw organic materials from manure or possibly also grass-clover pre-crops under suboptimal climatic conditions (Karalus, 2000; Radtke et al.,2000). Besides such negative effects remarkably positive effects of the use of straw mulch were found. On the one hand, straw mulch applications reduced potato virus Y infestation (Saucke and Döring, 2004) while at the end of the potato season the straw reduced nitrogen leaching (Döring et al., 2005).

After emergence of the potato the haulm and roots develop simultaneously. Haulm development is strongly affected by the nitrogen supply / availability in the first weeks after emergence (Harris 1992; Marschner 1995; Neuhoff 2000; van der Zaag, 1992; Vos 1995) and by the time of flowering (roughly six weeks after emergence) when the main bulking period starts a leaf area index (LAI) of 2.5 - 3 is needed to allow for optimal bulking (van Delden, 2001; Marschner, 1995). We have found that for a potential yield of 35 t ha^{-1} the crop needs to take up 110 – 130 kg N ha^{-1} during main foliage growth until start of tuber bulking (Schulte Geldermann, et al., unpublished) and an N need between 27 and 35 per 10t of yield has been reported in organic systems (Möller 2000). However, in high nitrogen-input conventional systems uptakes of 40-50 kg N per 10t of yield have been reported (Harris, 1992; Marschner, 1995; van der Zaag, 1992). It appears that N-use efficiency might be higher in low-input systems.

A too abundant haulm growth (high nitrogen supply) delays tuber initiation and crop maturation (Harris 1992; Marschner 1995; Millard and MacKerron, 1986). Excessive haulm growth may also prolong the duration of leaf wetness favouring the formation of spores, spore germination, and infection by the early and late blight pathogens (Radtke et al., 2000; Stevenson, 1993; Wright, 2002).

For plant protection in organic potato production, only few effective pesticides are available. The most important insect pest, the Colorado potato beetle (*Leptinotarsa decemlineata*) has to be managed preventively by reducing initial populations in the field through crop rotations and a minimum distance between fields in successive years of ideally about 100m. Remaining populations can be controlled in organic potato production with commercially available products based on *Bacillus thuringiensis var. tenebrionis* (Bt) or extracts of the Neem tree (see, e.g. http://www.bba.de/oekoland/index.htm). For fungal or bacterial diseases, on the other hand, there is currently no treatment available that reliably reduces diseases with the exception of copper based fungicides. While Copper fungicides reliably work as contact fungicides if applied preventively, their environmental side effects during production (mining) of copper and also in the soil and especially towards aquatic environments are unacceptable (Alloway, 1995) in general and especially when considering organic principles. Therefore, these fungicides are already prohibited in several European countries (Scandinavia and the Netherlands) and severely limited under German and Swiss organic regulations (a maximum of 3 and 4 kg Cu per ha and year are allowed, respectively) (Tamm et al, 2004). Under EU organic regulation 2092/92 (amended with prescription Nr. 473/2002 from March15th 2002) until 2005 up to 8 kg ha^{-1} and year elemental copper are allowed and from 2006 to 2008 up to 6 kg ha^{-1}with the final aim of prohibition. In parallel, the Swiss forecasting system that had been designed for the application of systemic fungicides has by now been expanded to allow for the optimisation of copper based contact fungicides in organic farming (Musa-Steenblock and Forrer, 2005).

In organic potato production the growing period is often limited due an early death of the haulm due to disease and pest attack, especially by late blight, caused by *Phytophthora* *infestans*. To extend the post- emergence growth period in organic potato production, it is of importance to plant physiologically old (chitted) seed tubers and to plant as early as weather and soil conditions allow (Karalus and Rauber, 1997). As a consequence, soil temperatures during early potato development are often not very high and thus impede mineralization of nutrients from the organic residues in the soil during the critical period after crop emergence.

There is virtually no firm data available on the effects of *P. infestans* on yields in organic potato production (Tamm et al, 2004). This is due to the fact that no effective organic pesticides are available to achieve a healthy control in yield loss studies. More typically, comparisons are made between an untreated control and potatoes treated with substances allowed in organic farming. Depending on site, year, and time and type of application up to 25 % yield increases have been achieved with copper fungicides or various plant strengtheners (Möller and Meinck, 2003, Kainz and Möller, 2003). Yield increases in comparison to an untreated control cannot be used for yield loss analysis, however, as on the one hand the efficacy of the treatments depends on disease pressure, and, on the other hand, the yield potential at the site is not known.

An alternative approach to yield loss analysis in the absence of a healthy control was taken by Bouws-Beuermann (2005) by making use of the typical natural spatial variation in late blight severity across a field. They divided their experimental plots into multiple row sections of 3 to 6 m length which were all assessed separately for disease severity over time and also harvested separately. This approach resulted in subplots differing up to three-fold in area under the disease progress curve. Depending on cultivar and year, between 0 and 24 % of the variation in yield could be explained by area under the curve, indicating that factors other than disease play a dominant role in determining yields.

To assess the socio-economic impacts of late blight in organic production and the possible impacts of a copper ban, within the EU- Blight-MOP Project (**B**light **M**anagement in **O**rganic **P**otato Production, see http://www.ncl.ac.uk/tcoa/producers/research/blightmop/) a survey on organic potato growing was conducted in seven European countries involving 115 farms (Tamm et al, 2004). It became evident that yields are severely limited in organic farming and a majority of farmers claimed that they suffered yield losses due to late blight. Where it is legally allowed, farmers do therefore use copper fungicides. Late blight and black scurf are currently the most important diseases in organic farming. In addition, common scab (caused by *Streptomyces scabies*), silver scurf (*Helminthosporium solani*) and sometimes soft rot (caused by *Erwinia carotovora*) may cause serious problems.

While diseases appeared to be an important limitation to organic potato production, the data from the survey indicate that plant nutrition is at least as important. For example, on the farms surveyed organic manure inputs ranged from 0-350 kg N ha^{-1} (with a few extremely high values above 400kg) with the majority applying between 100 and 200kg. However, relating the inputs to the available N in the surveyed fields revealed that the amount of available N was below 100kg in all countries except France and the results clearly suggest that yields in organic farming are in large part limited by nutrient supply. A similar picture emerged for K-inputs which also tend to be below the recommended rates (Tamm et al, 2004).

The purpose of this paper is to present some data on the interactive effects of climatic conditions, nutrient supply and disease on the yield of the potato cultivar Nicola (a mid-early main-crop potato). The data are drawn out of a total of five experiments conducted from 2002-2004 under various experimental conditions with and without application of copper fungicides.

2.2. Materials and Methods

In all experiments described, the cultivar Nicola (breeder Saatzucht Soltau/Bergen, Germany) was used. From 2002 to 2004 Nicola was grown at the experimental farm Hebenshausen (Heb) of the University of Kassel (annual mean temperature 7.9 ^oC, precipitation 619mm). Pre-crops were either grass-clover (GC) or winter wheat (WW) and in addition, in 2004, spring oats. No additional fertilisers were used. In all three years, there were four replications for all treatments planted. However, because of inclement weather interrupting planting operations in 2002, planting dates varied by 3 weeks among replications (Table 1). Plot sizes varied from 6 * 10m to 18 * 15m.

In addition to the site in Hebenshausen, in 2004, Nicola was grown in two sections of a nearby field (Eich, same climatic conditions) and in two sections of a farmers field (Etze, mean Temperature 8.7 ^oC, ppt 645 mm) in unreplicated plots of 15 * 30m. In Eich, in one section of the field the pre-crop was cabbage that had been harvested while in a second section of the field the cabbage had not been harvested due to marketing problems (Cab2). In Etze, the pre-crop was winter wheat.

At all sites, Copper Hydroxide (Cuprozin) was applied between 4 and 5 times per season at a rate of 500g Copper and 400 l/ha per application. Application dates were based on the internet based late blight warning system as soon as the first blight lesions were observed in the area immediately surrounding the experiments. However, in 2002 and 2004, inclement weather conditions often prevented optimal timing of the applications.

Soils were analysed prior to planting in late March/ early April and between 4 and 6 times during the growing season at each site concentrating on the time of maximum growth of the potatoes in May - July. Nitrate-N was determined in 0-60cm depth according to a standard assessment method (Schinner et al., 1996).

Plots were checked regularly until the beginning of the late blight epidemic. After this, disease was assessed twice weekly on five plants per plot (2002 and 2003) and in eight to 16 plot sections covering 7.5m length of a row in 2004. Percent diseased leaf area was estimated following the key of James et al. (1971).

Area under the disease progress curve (AUDC) was calculated per plot in 2002 and 2003 and per assessment site in 2004 based on the equation given by Kranz (1996).

At Heb and Eich daily mean temperatures and precipitation was measured with a local weather station while for Etze data from the German Weather service were obtained.

As the data from Eich and Etze are based on unreplicated plots for Heb the replication means were used for the years 2003 and 2004. For Heb 2002, this was not possible, however, because of the different planting dates and extremely different epidemic conditions among replications. Therefore, plots were used separately in the regression analysis.

The following parameters were derived for a multiple regression analysis:

- Growth duration from planting until disease severity of 60 % diseases leaf area (determined visually from the disease progress curves) was reached (**Days**)
- Temperature sum (sum of daily mean temperatures) from planting until 60 % disease severity (**Ttot**)
- N-min at day 10 after emergence (**N10**)
- N-min at day 21 after emergence (**N21**)
- Disease in copper treated plots compared to non-treated plots within site (**Disred**)

It is discussed that until 60 % diseased leaf area, there will be no substantial yield loss (Möller, 2000). Also, data from sequential harvests of the cultivar Nicola in Heb04 showed that there was no more yield increase after disease severity of about 60 % had been reached (Bruns et al., unpublished). Therefore, 60 % was used as the cut-off point to determine the growth duration of the crop. In 2003, almost no late blight occurred the crop was defoliated on Aug 12. Therefore, the growth duration until defoliation is taken instead.

Relative disease was calculated as the proportion of AUDC in copper treated plots compared to untreated plots.

Data were analysed with Statistical Analysis Systems (SAS, 1986) using stepwise forward multiple Regression maximising R^2 (MAXR option). The procedure first selects the best regression based on a single parameter, then based on two factors and so on until no further improvement in R^2 can be achieved by adding a factor. For final model selection, the residual plots together with the tolerance values of the co linearity analysis were also considered.

Table 2. 1. Variation in growing conditions for the cultivar Nicola in three sites in different years and after various pre-crops: earliest and latest date at which 60 % diseased leaf area (60 % DLA) was reached in each experiment, ranges for growth duration (days) temperature sums (Ttot), soil N-min contents up to 60 cm depth (kg/ha) at day 10 and day 21 after crop emergence (N10 and N21, respectively) and disease reduction observed. The lowest (min) and highest (max) observed value at a given site is shown for each parameter.

Site, Year	Planting Date	Pre-Crops[1]	60 % DLA[2]		Days		Ttot[3]		N10		N21		Disred[4]	
			Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Heb02	23.4. / 15.5.	GC, WW	30.7.	19.8.	80	109	1465	1858	75	125	67	100	-0.06	0.48
Heb03	15.4.	GC, WW	12.8.	12.8.	119	119	2000	2000	85	105	65	70	0.64	0.89
Heb04	16.4.	GC, WW, Oat	25.7.	31.7.	100	106	1371	1451	60	110	60	110	0.10	0.40
Eich04	3.4.	Cab1, Cab2	21.7.	27.7.	109	115	1375	1474	100	190	250	250	0.21	0.32
Etze04	19.4.	WW	28.7.	4.8.	100	107	1372	1503	85	85	100	100	0.40	0.44

[1] Pre-crops were: GC = grass-clover, WW = Winter Wheat, Cab1 = cabbage, Cab2 = cabbage that was not harvested.

[2] In 2003 the crop was defoliated as late blight reached only 35 %.

[3] Sum of daily mean temperature from planting to 60 % disease severity. In 2003, until defoliation.

[4] Disease reduction is the Area under the disease progress curve (AUDC) with copper application divided by AUDC without copper application

2.3. Results

The climatic and growing conditions varied considerably among sites and years resulting in a wide database with respect to growth duration as influenced by *P. infestans* epidemics (Table 2. 1). The maximum temperature sum from planting to 60 % disease severity was 1858 during 108 days in 2002. In contrast, 2004 was much cooler, with a maximum of 1503 in 107 days in Etze and only 1474 in 115 days in Eich, respectively (Table 2. 1). Generally, very dry and hot conditions during June and July 2003 resulted in very slow disease development up to a maximum of 35 % when the crop was defoliated. Therefore, in 2003, the temperature sum was calculated up to defoliation which was 2000 during 119 days and there was no variation in growth duration and Temperature sums among treatments in that year.

Late blight was first observed on July 8 in 2002 and on July 16 and 14 in 2003 and 2004, respectively. In 2002, conditions for the disease were very favourable in July and epidemics in some plots progressed extremely fast. Depending on planting time, copper application and epidemic situation, the growth durations and temperature sums varied from 81-108 days among the different plots. The variation was much smaller among sites and pre-crops in 2004, in contrast (Table 2. 1).

The Nitrate-N dynamics also varied greatly among years, sites and pre-crops with the extremely high values of 250kg N_{min} per ha 21 days after emergence (N21) after pre-crop cabbage in Eich04reaching levels that are more common to conventional agricultural conditions (Table 2. 1).

Copper sprays did not always result in disease reductions and in one case in 2002 there was even a slight increase (Table 2. 1). However, overall the growth duration of sprayed plots was increased between 0-11 days in comparison to unsprayed plots and there was a highly significant correlation (R^2 = 0.66) between disease reduction and additional growing days (Figure 2. 1).

Total yields varied between 11.7 t ha^{-1} in Heb02 in a plot planted late after pre-crop winter wheat and hit early by late blight and not protected by copper sprays and 41.0 t ha^{-1} after grass clover in Heb03 (Figure 2. 3). There appeared to be no yield benefit due to the extraordinarily high N contents in Eich04 (see Table 2. 1) where total yields ranged between 29.4 and 40.5 t ha^{-1} (Figure 2. 3).

The multiple regression procedure yielded different results depending on the inclusion or exclusion of the extreme N-values of Eich in 2004. When omitting these data points a clear picture emerged (Table 2. 2). In the single parameter model, disease reduction correlated best with total yield. However, only 26.30 % of the variation in yield was explained by the model (R^2 = 0.2630). Also, plotting disease reduction versus yield (Figure 2. 2) shows that in the case of no disease reduction yields varied from the lowest observed yields to almost the highest. In the best two-parameter model, growth duration (days) together with the soil mineral N content at 21 days after emergence (N21) could explain 42 % of the variation in yield. The correlation could be slightly improved by adding the temperature sum (Ttot) and replacing N21 with N10 (R^2 = 0.57). While adding disease reduction did not improve the correlation substantially (R^2=0.61) (Table 2. 2) the residual plot of the four-parameter model revealed a much better and less biased fit than the three-parameter model. On the other hand, the correlations between the parameters used were not excessively high (tolerance values between 0.49 and 0.88) while in the five-parameter model the tolerance values for Ttot, N10 and N21 became unacceptably low (Table 2. 2). The predicted yields based on the four-parameter model are plotted against the observed values in Figure 2. 3. From the figure it can be seen that the yields in 2002 were much lower than in 2003 an 2004. Based on the model prediction (Table 2. 2), the predicted yields for Eich04 were between 36 and 57 t ha^{-1} (Figure 2. 3, circled data points) i.e. between 7 and 20 t higher than realised.

When the data from Eich04were included, the stepwise inclusion of parameters into the model started with growth duration followed by the temperature sum and disease reduction. Only in the model with four or five parameters the N-values became relevant and overall their importance was much reduced.

In 2004, detailed disease assessments were available for 8 or 16 assessment sections per plot with and without copper treatment that were subsequently harvested separately. Thus, it was possible to assess yield loss relationships by site (Figure 2. 4). While in three cases, two in Etze and one in Eich between 29 and 47 % of the variation in yield could be explained with AUDC, in the other four cases there was no correlation between disease and yield.

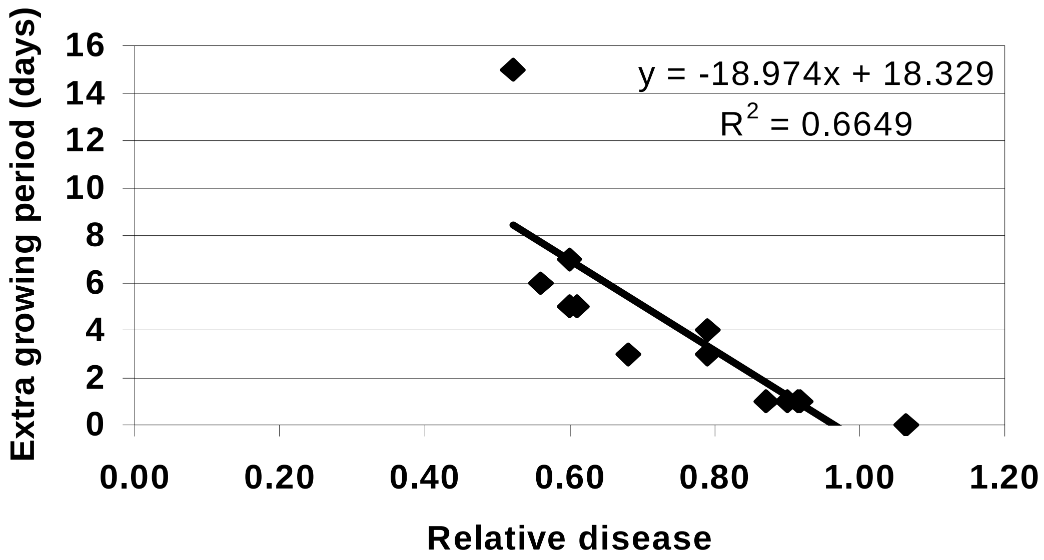

Figure 2. 1: Effects of disease reductions due to copper applications on the growing period of the potato cultivar Nicola in different sites and years. Data from 2003 are omitted as the crop was defoliated.

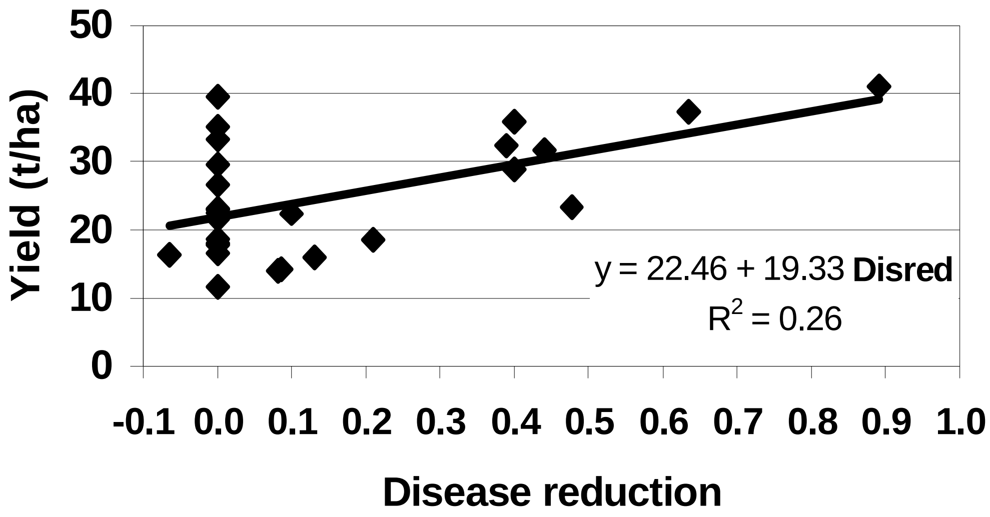

Figure 2. 2: Effects of disease reduction on yield of the cultivar Nicola after various pre-crops excluding the data from Eich04

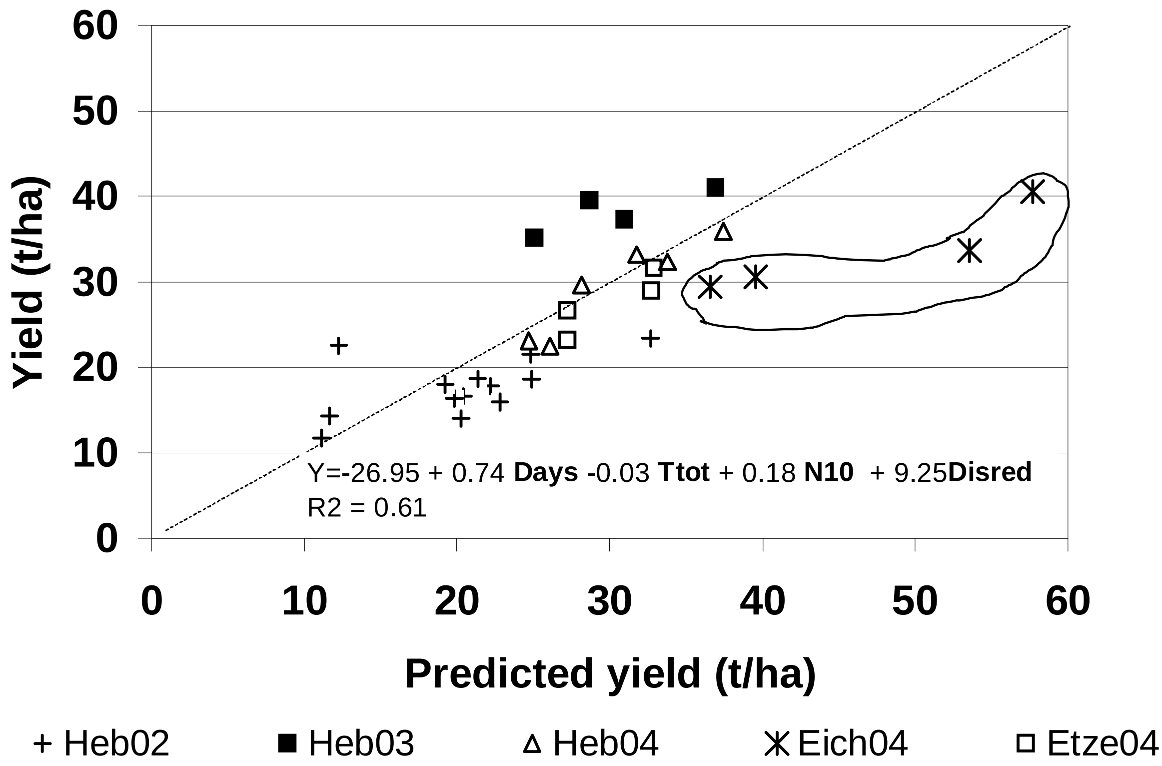

Figure 2. 3 Results of the multiple regression of total crop yield per ha on growth duration (Days), Temperature sum between planting and 60 % disease (Ttot), soil Mineral N contents in 0-60cm depth at day 10 after crop emergence (N10), and disease reduction due to copper application (Disred). The regression is based on the values excluding the data from Eich04. Based on the model, predicted values for Eich04 are overestimated (circled data points) due to the extreme N-levels at that site (see Table 2. 1). The 45^{o} line represents the expected values.

Table 2. 2: Results of multiple regression of total yield optimising for R^2 with one to five variables excluding the data from Eich04. Variables are Growth duration (days) Temperature sums (Ttot), N-min measurements at day 10 after crop emergence (N10 and N21, respectively) and disease reduction (disred). Co linearity analysis for Model 4. See Materials and Methods for details.

Model	Parameter	Estimate	Error	SS	F-value	P-value	R^2	Tolerance[1]
1	Intercept	22.46	1.27	19135	310.56	<.0001	0.26	
1	Disred	19.33	4.48	1148	18.63	<.0001		
2	Intercept	-60.43	14.4	866	17.61	0.0001	0.42	
2	Tage	0.59	0.11	1311	26.64	<.0001		0.89
2	N21	0.3	0.06	1083	22.02	<.0001		0.89
3	Intercept	-40.92	11.27	498	13.17	0.0007	0.57	
3	Tage	0.88	0.12	1949	51.57	<.0001		0.62
3	Ttot	-0.03	0	1238	32.76	<.0001		0.62
3	N10	0.22	0.05	647	17.11	0.0001		0.97
4	Intercept	-26.95	12.35	165	4.76	0.0339	0.61	
4	Tage	0.74	0.13	1127	32.48	<.0001		0.49
4	Ttot	-0.03	0	1084	31.23	<.0001		0.59
4	N10	0.18	0.05	377	10.85	0.0018		0.88
4	Disred	9.25	3.96	189	5.44	0.0238		0.72
5	Intercept	-17.67	15.06	48	1.38	0.2467	0.62	
5	Tage	0.79	0.14	1151	33.28	<.0001		0.44
5	Ttot	-0.03	0.01	611	17.67	0.0001		0.21
5	N10	0.26	0.09	270	7.8	0.0075		0.3
5	N21	-0.12	0.12	40	1.15	0.2885		0.19
5	Disred	9.4	3.96	195	5.63	0.0217		0.72

[1] The tolerance values of the co linearity analysis are given for the models with more than one parameter. The maximum value of 1 indicates no co linearity among parameters.

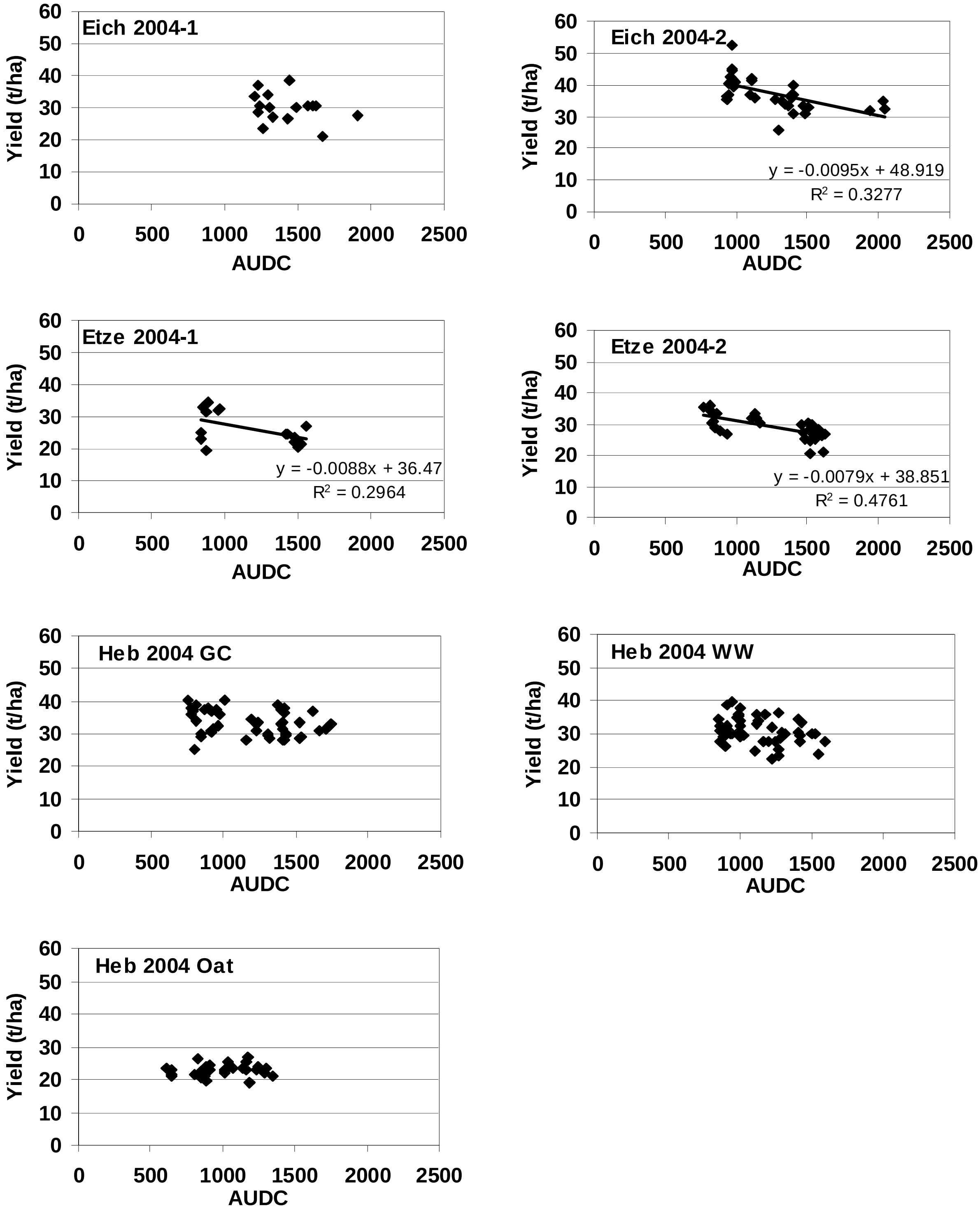

Figure 2. 4: Effects of area under the disease progress curve (AUDC) on total yield of the cultivar Nicola in three different sites with different pre-crops in 2004. Disease was assessed in 7.5m long row sections. The same sections were harvested separately. The sites are listed in Table 1 where Eich1 has Cabbage as pre-crop and Eich2 unharvested cabbage.

2.4. Discussion

From the experimental work it became clear that while the use of copper fungicides in most cases did slow down epidemics, the gains in growth duration were very low. Results on the yield benefits due to spraying were ambiguous. Only the inclusion of other environmental factors over time made it possible to interpret the data. Overall, yields of the cultivar Nicola could be predicted reasonably well when including information on growth duration and the temperature sum from planting until 60 % disease severity was reached, soil mineral N contents at 10 days after emergence, and disease reduction due to copper application. An exception was the site Eich04 where the N levels in the soil had been unusually high and for which the model was not adequate.

Yields in Eich04were surprisingly low in comparison to the other sites with 29-40 t ha^{-1} despite the extremely high N-values (up to 280kg ha^{-1} on June 3) and the long growth duration. However, relative to the other sites crop death was early. The crop had been planted on April 3 2004, 13 to 16 days earlier than in Heb04 or Etze04 (Table 2. 1) and it also emerged earlier.

It is likely, that several factors interacted to limit the yields in Eich04. First, due to the high N-levels an unusually high leaf mass was built up early on. While this is decisive for the potential yield, likely tuber initiation was delayed as has been described above (Harris, 1992; Marschner, 1995; Millard and MacKerron, 1986; Voss, 1995). Late blight infections were stronger and epidemic progress faster in Eich04 than in the other sites in 2004 or in 2002 (60 % severity reached within 7 to 13 days in Eich04, 9 to 19 days in Heb and Etze04, up to 35 days in Heb02, data not shown). This could in part have been due to the very dense crop growth which probably led to a more favourable microclimate for late blight development. Thus, it is likely that the crop died too early before the potential yield was reached. With N-levels rising well above 200 kg ha^{-1} in Eich04, it is likely, that the crop would have behaved like a conventional crop and it would have continued to increase its tuber mass until mid-August in the absence of late blight. Möller (2002) reported that depending on available N tubers stop growing between mid July (70-90 kg N-uptake), end July (110-140kg N-uptake) and mid-August (140-180kg N-uptake). The significant effect of AUDC on yield in Eich04 site 2 (Figure 2. 4) is in line with this prediction. At that site, copper had reduced AUDC by 32 %. The lack of a significant effect of AUDC on yield in site 1 in Eich04 can be explained by the fact that disease pressure was overall higher there due to an early disease focus and copper less effective (reduction of 21 %).

The lack of significant correlations between AUDC and yield in Heb04 (Figure 2. 4), where N-levels were much lower than in Eich04 probably indicates that at the levels of N supplied tuber growth had already largely ceased by the time late blight became limiting and the measured yield differences are almost entirely due to differences in N. On June 3, 16 days after emergence nutrient peaks of 70, 110, and 140 kg N ha^{-1}were measured after pre-crop oats, winter wheat, and grass clover, respectively with levels dropping to about 20kg ha^{-1} by July 15 after all pre-crops. This indicates that probably between 40 and 70 more kg N ha^{-1} were taken up by the crop after winter wheat and grass clover providing for more than 10 t extra yield potential after these pre-crops based on the results by Möller (2000) that between 27 and 35 kg N uptake are needed per 10 t of yield. Total yields after pre-crop oats were between 22 and 23 t ha^{-1} while after winter wheat and grass clover they reached 29-32 t ha^{-1} and 33-36 t ha^{-1}, in the absence and presence of copper, respectively, corresponding well with that prediction. Although leaf area was not measured in the field, there were clearly visible differences among the different pre-crops. For example, canopy closure was never reached after pre-crop oats but after winter wheat and grass clover. Also, after oats the crop flowered almost two weeks earlier than after the other pre-crops.

While the N-levels in Etze04 were similar to those in Heb04 after winter wheat, in Etze disease did affect yields significantly. While N-levels were comparable (**Table 2. 1**, the soils at Etze were considerably poorer in general quality than in Heb (52 versus 76 Soil Points, respectively on a scale with a maximum of 100, based on the official soil map data available to the farmers). This could have led to differences in N-uptake dynamics by the crop and to differences in tuber growth dynamics. If tuber formation was delayed in Etze in comparison to Heb then effects of disease should have been stronger. Without exact measurements on crop N uptake and sequential yields, it will not be possible to determine the reasons for the different behaviour.

However, data on N-uptake by the crop are needed for a more exact prediction of yield potential and analysis of yield losses.

Due to the interactions with N-supply it is thus not surprising that the yield-loss relationships we measured were either non-existing or weak (Figure 2. 4) which is in line with previous observations by Bouws-Beuermann (2005). The slopes of the significant regressions were very similar and the intercepts varied according to the N-supply of the sites. However, predicting yield potential from the regressions would be an over interpretation. When analysing different varieties with this method, slopes varied indicating more or less severe effects of late blight on yield (Bouws-Beuermann, 2005).

Interestingly, in this study, the slope was three times steeper in a more resistant (AUDC = 1050) but later bulking cultivar than in a susceptible (AUDC = 2500) early bulking cultivar indicating a strong cultivar interaction. Obviously, the effects of disease were stronger on the later bulking cultivar.

Currently, there are only few means available to organic farmers to reduce late blight or yield losses in the absence of copper. The most efficient means is the use of resistant varieties. Field hygiene, pre-sprouting and early planting reduce the risk of yield losses due to late blight. Depending on soil conditions (moisture and temperature, early planting may lead to increased problems with black scurf, however. Overall, only resistance and possibly hygiene can reduce disease progress or initial infection while pre-sprouting only is a measure to reduce yield losses through a partial escape because bulking of the potatoes starts earlier before onset of late blight epidemics (Karalus, 1997). None of the alternative formulations based on substances allowed in organic farming (plant extracts, microbial products, clay or other minerals etc.) and tested within the EU Blight MOP project has so far led to consistent reductions in disease severity (Stefan et al., 2003; Blight MOP annual report 2005, unpublished). However, several studies indicate that there is a tendency that effects are more likely to occur when disease pressure is moderate (Neuhoff et al., 2003; Schliephake et al.2001). Thus, clearly, any cultural method that reduces disease pressure will improve the likelihood for an alternative spray to be of benefit.

One way to reduce disease pressure is by reducing the overall amount of susceptible host tissue, i.e. potato density, in an area. Increases in planting distance within the limits of practical relevance have failed to contribute to disease control. Alternatively, various diversification strategies can be used to reduce the density of susceptible plants. These strategies are based on different cropping patterns such as cultivar mixtures, alternating rows or strips of different cultivars, and strip intercropping of potatoes with other non-host crops.

Cultivar mixtures had moderate effects reducing focal and general epidemics under low inoculum pressure (Finckh et al., 2003; Garrett and Mundt, 2000). Similarly, when planting different potato varieties in alternating rows, the best results were obtained for the slowest epidemics (Andrivon et al., 2003). When intercropping potatoes with other crops, the microclimatic conditions within the crop will be affected by the type of intercrop and the width of the potato beds, which may also affect late blight severity and its spread. Consistent disease reductions were obtained when potatoes were strip intercropped with grass clover or, to a lesser degree with spring wheat especially when the strips were arranged perpendicular to the prevailing wind direction (Finckh et al., 2004). In this case, several mechanisms worked synergistically within the system. First, inoculum was carried out of narrow strips and lost from the potatoes to the non-hosts. Second, probably, the neighbour crop acted as a filter to incoming inoculum reducing disease spread from strip to strip. Depending on the neighbouring crop, the microclimate within the strips was altered resulting in changes in disease severity and in patterns of disease spread (Bouws-Beuermann, 2005).

One of the benefits a farmer has by not growing all his or her potatoes in one large field but rather in several separated fields is that usually initial disease is not uniformly distributed and the more the potato crop is subdivided the more disease spread between fields is reduced and single fields have an increased chance of escaping early infections. The chances of being infected by incoming inoculum or of harbouring an infected seed tuber are naturally reduced in small isolated fields in comparison to large fields**.**

2.5. Conclusions

In conclusion, several points emerge from the literature and the presented results: In organic farming, yields are foremost limited by nutrient availability in spring and early summer in the system. This has been shown in several experiments at University of Kassel (Bruns et al, 2003, Schulte-Geldermann et al., unpublished) and it was indirectly concluded from on-farm observations by Möller (2000). In general, late blight reductions through copper based sprays are limited and increase with reduced disease pressure. Thus, copper fungicides will only lead to yield increases when early bulking highly nutrient efficient potato varieties are used in a cropping system that minimises disease pressure to start with and the soils in spring and early summer are provided with sufficient warmth and water to allow for timely mineralization. To complete the forecasting tool optimising copper fungicide application in organic farming (Musa-Steenblock and Forrer, 2005) it will be necessary to add and evaluate data on crop nutrient status, developmental stage and soil fertility to determine if the application of copper will be beneficial in a given situation.

Our data help explain why yield loss relationships cannot be transferred from conventional systems to organic systems and also indicate that often the effects of late blight on yield in organic farming are overestimated.

Resistance clearly remains the most important strategy against late blight in organic potato production. However, maybe even more important than resistance is the early development and bulking behaviour and the ability of a cultivar to make use of organic nutrients efficiently. In the absence of efficient organic pesticides it is possible to reduce blight pressure to a certain extent by arranging the crop in small narrow fields perpendicular to the main wind direction neighboured either by non-hosts or completely resistant potatoes.

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3. Effects of three organic fertilisers and two biostimulants based on plant and animal residues on nutrient supply, yield and plant health in organic potato and tomato production

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Abstract

At the field level, products manufactured from different raw materials such as seaweeds, pine needles, trees and herbaceous species or physically hydrolysed bovine fur and hair residues were applied as solid pellets or liquids, as fertilisers or biostimulant sprays, respectively. This paper presents as an example results from field trials of organically grown tomatoes and potatoes at the University of Kassel. Assessments were performed on yield and plant health aspects. In the experiments fertiliser products with nitrogen contents between 7 to 12 % resulted in comparable growth effects and at least as high or higher yields as obtained with horn meal fertilisers.

A combination of the biostimulants and a solid product based on plant raw materials reduced plant and fruit late blight and increased fruit number of open-field and poly tunnel grown tomatoes. In potato trials one biostimulant product increased yield in one of two years and also reduced black scurf (*R. solani)* infestation significantly.

It is concluded that especially the combination of well adapted liquid and solid products can have promising effects on crop performance.

Keywords: Organic fertiliser, biostimulant, plant nutrition, crop health

3.1. Introduction

For organic producers the two main challenges are disease and nutrient management. Both factors are limited by regulations that on the one hand prohibit the use of chemical fertilisers, especially nitrogen and, on the other hand, synthetic pesticides (EU-regulation 2092/91).

Plant nutrition in organic farming therefore relies on carefully designed rotations including ideally 25 % or more legumes in the rotation and the addition of organic fertilisers such as solid and liquid animal manures, green manures, and composts. With the exception of liquid manure these fertilisers are usually slow release and highly dependent on the soil moisture and temperature for mineralization processes that make the nutrients available to the plants.

However, N mineralization in central European countries in spring, when crop N demand is high, is usually slow due to the relatively low temperatures often leading to N deficiencies (Heß & Klein 1987, Van Delden 2001; Von Fragstein et al., 2005). Therefore, especially in high value vegetable crops external fertilisers that supply nutrients more rapidly such as hair meal pellets, molasses, horn and legume meals etc. are also used. Nonetheless, external organic fertilisers differ in nutrient composition due to differences in the basic raw material and formulations (Körber et al., 1994; Laber 2000, 2001; Müller & Von Fragstein, 2003).

The input of external organic fertilisers is limited to 170 kg N ha^{-1} by the EU directive 2092/91. Some German organic farming associations have even stricter limitations in the amounts of additional external nitrogen that are permitted within a season (e.g. Bioland, Demeter, and Naturland: 40 kg N ha^{-1} and year).

Farmers and researchers have long been searching for ways to enhance nutrient availability and uptake under organic conditions by developing new organic fertilisers and biostimulants. For many fertilisers it is claimed by the manufacturers that they stimulate the activity of soil microbes, which are responsible for the mineralization of organic matter and for the gradual slow release of nitrogen and other macro- and microelements. Indeed, slow release N fertilisers and high soil organic matter can lead to greater N supplying capacity well into the growing season, when N demand by plants is still high in addition to reducing N leaching (Jackson & Bloom 1990; Burger & Jackson 2003; Koivunen & Horwath 2005).

Positive plant growth regulators or metabolic enhancers are referred to as biostimulants (Miller 1990). For example, seaweed extracts and humic substances contain identifiable amounts of plant growth hormones, such as auxins, gibberellins and cytokines, as well as modified amino acids like betaines which can affect plant physiology when applied in small quantities (Brain et al. 1973; Blunden 1977; Williams et al. 1981; Blunden et al. 1992; Nardi et al. 2002; Canellas et al. 2002; Zhang and Ervin 2004). However, e.g. seaweed extracts are unlikely to remedy a severe mineral deficiency and the appropriate element should be applied, preferably in combination with seaweed extract, to further stimulate growth (Aitken& Senn, 1965 Blunden 1977).

Besides a moderate to high demand of phosphorus and potassium, both potatoes and tomatoes need considerable amounts of nitrogen to produce acceptable yields. However, they differ in the time of main nitrogen demands. Potatoes require about 60- 80 % of their nitrogen in the first six to eight weeks after crop emergence, during major vegetative growth and prior to tuber initiation (Marschner 1995; Harris 1978). As potatoes have a relatively poor root system, they are only able to take up nutrients from the top 60 cm of the soil (Schmidtke et al. 1999; Schönberger & Erichsen 1994). Therefore, it is important to provide the nutrients in time in the top soil. However, a high nitrogen supply prolongs vegetative growth, delays tuber initiation and the onset of the linear bulking phase and consequently crop maturation (Harris 1978; Van Der Zaag 1992, Marschner 1995; Möller 2002; Haase 2007). Excessive haulm growth may also prolong the duration of leaf wetness and thus favour the formation of spores, spore germination, and infection by the early and late blight pathogens and therefore increases the risk of considerable yield losses under organic growing conditions.

In contrast to potatoes, tomatoes require nutrients throughout their long vegetation period. Besides the importance of potassium during fruit development, levels of nitrogen also need to be maintained and the concentration of nitrogen before initiation of the first flower truss is of crucial importance in determining yield (Carpena et al. 1988).

In an EU CRAFT project (Final Report to EU COOP-CT-2004-508458) running from March 2004 to March 2006, an international consortium of producers of environmentally benign crop inputs (BFPs: Biological Food for Plants), RTD contractors (in EU-projects for Research Technology & Development**)** and end users evaluated the production and use of BFPs manufactured from different raw materials: bovine hides, trees, and herbaceous plants. The BFPs evaluated were produced by extracting ‘biologically active compounds’, which are thought to improve crop growth and vigour or protect against pests and diseases by improving crop health and plant disease resistance. The aim was to reduce the need for mineral fertilisers and pesticides. At the field level, the BFP products were applied as solid pellets or liquid, as fertilisers or as biostimulant sprays, respectively. Some experiments were continued at the University of Kassel in 2006 and 2007.

In this paper we report the results from trials conducted at the experimental stations of the University of Kassel on the effects of several organic fertilisers and two biostimulants on organically grown potatoes (*Solanum tuberosum*) and field and poly tunnel grown tomatoes (*Lycopersicon lycopersicum L.*). The fertilisers BioFeed Ecomix (BFE), BioFeed Basis (BFB) (AgroBio Products, Wageningen, NL) and BioIlsa 12,5 Export (BI 12) (ILSA Group Arzignano, Vicenza, Italy) were tested alone or in combination with the biostimulants BioFeed Quality (AgroBio Products, Wageningen, NL) and AUSMA (Biolat, Salaspils Latvia).

In the tomato trials, the two BFP fertilisers were compared to an organic standard (horn meal). Trials were conducted in the field for two years. An additional trial was conducted with poly tunnel-grown tomatoes. In additional laboratory experiments, detached leaves of young tomato plants and also from the adult poly tunnel grown plants were inoculated with *P. infestans* to test the effects of treatments on plant resistance properties.

In the potato trials, in 2004, the fertilisers BFE and BI 12 were compared at 75 kg N input ha^{-1} using two very early potato cultivars Salome and Velox. Due to the very short growth duration effects of the organic fertilisers were minimal. To test the effects during a longer growing period, in 2005 and 2006 the mid-early cultivar Nicola was used instead. In the second year a higher fertilisation level (150 kg N ha^{-1}) was included in addition to an unfertilised control. As there were no differences between the two fertilisation levels, in the third year, only one application level was used. The N-input level in the third year was reduced to 40 kg N ha^{-1} to adjust for a different position of the experimental field in the crop rotation (second instead of fourth year in 2004 and 2005 after N – fixing grass clover ley). Instead, effects of fertiliser placement (strip vs. broadcast) were assessed. Also, like with tomatoes horn meal was added as an organic standard fertiliser to which the two new fertilisers were compared.

In detail, the following questions were addressed: What are the effects of the various fertilisers and fertiliser levels (i) on soil nutrient turnover and crop N uptake dynamics; (ii) on crop yield and crop growth dynamics, and (iii) on crop growth, vigour, and health?

3.2. Materials and Methods

3.2.1. Experimental site

Field trials were conducted on the experimental farm of the University of Kassel in Hebenshausen, located about 10 km to the north-west of Witzenhausen, at an average height of 250 m above sea level. The soil type of the experimental field is a homogeneous deep gleyed loess-leached brown soil. The German ”Reichsbodenschätzung” (land evaluation) qualified the index of the soil at 74 points (max. 100 points).The mean annual precipitation amounts to 612 mm and the average temperature is 7.9° C (Brandt et al. 1998).

3.2.2. Products

Fertilisers

Biofeed Basis (BFB) is a complex mix of plant proteins enriched with soft ground rock phosphate, potassium sulphate and calcium carbonate. Plant material derived from seaweed, potato, maize, soybean and sesame. Many micro nutrients are present due to the use of seaweed. All compounds are GMO - free and allowed in organic farming according to the EC – regulation 2092/91. In 2004, BioFeed Ecomix (BFE) was used which also contained some animal derived material (bone and horn meal) and thus had a higher phosphorus content (Table 3. 1). However, the product was taken off the market in 2005 as the company decided to concentrate on plant derived products only. The products were applied as pressed pellets of 3 mm diameter.

BioIlsa 12,5 EXPORT (BI 12) is an organic nitrogen fertiliser manufactured through physical hydrolysis of leather shavings of bovine hides devoid of phosphorus and potassium (Table 3. 1). The product was applied as pressed pellets of 4 mm diameter.

Table 3. 1: Analyses of fertilisers Biofeed Ecomix, Biofeed Basis and BioIlsa 12,5 Export

	BF Ecomix	BF Basis	BioIlsa 12,5 Export
N	7.50%	7.50%	12.00%
Organic N	7.40%	7.40%	
Phosphorus (P_2O_5)	4.00%	2.00%	
Potassium (K_2O)	4.00%	4.00%	0.20%
Organic matter	72.10%	74.10%	70.00%
Carbon	40.00%	43.00%	40.00%
C/N ratio	5.3 : 1	5.7: 1	3.3 : 1
Moisture	< 10 %	< 10 %	4%

Biostimulants

”AUSMA” is obtained by water extraction from pine and spruce needles and is recommended as a stimulator for plant rooting, growing, flowering and productivity. ”AUSMA” contains natural growth stimulators, microelements, water-soluble vitamins and other biologically active substances (Biolat, 2004).

BioFeed Quality (BFQ) is a watery multi-compound extract from 2 types of seaweed: *Ascophyllum nodosum* and *Fucus spp* (20 % (w/w)) reinforced with humic and fulvic acids (2% (w/w)). The seaweed harvested from the Atlantic Ocean (France), is washed and dried without addition of any substance for preservation. Subsequently, the dried seaweed is ground and put into a large vessel together with 2 % dried thyme (*Thymus vulgaris*). Water is added and the correct pH for extraction is regulated by using fulvic acid. After the extraction step, the sludge (water + ingredients) is filtered. In this filtration step a filter cake is obtained and a clear, particle free solution (the extract) (AgroBio Products, 2007). Nutrient contents are < 0.1 %: and 0.11 % K_2O of dry matter mass (Analysis of BioFeed Quality according the Institut für Düngemittel und Saatgut (LUFA) in Hameln, Germany).

3.2.3. Tomato trials

3.2.3.1. Field trials 2005 and 2006

Trials were set up in a randomized complete block design with four replications. Each plot was planted with eight plants. The distance between and within the rows were 80 and 60 cm, respectively. The medium late blight susceptible cultivar Matina obtained from Dreschflegel, e.V. Witzenhausen Germany (heritage seed) was used in both years. The late blight tolerant cultivar Philovita (B. Nebelung/ Kiepenkerl, Everswinkel, Germany) was included in 2006. Plants were transplanted at the end of May in both years.

In 2005, the pre-crop was winter wheat (*Tritcum aestivum L. cultivar Capo; WW*), in 2006 it was grass/ clover ley. Prior to planting nitrogen content of the soil was about 58 kg and 72 kg N-min ha^{-1} (0-60 cm soil profile) in the two years, respectively.

There were four and three treatments in 2005 and 2006, respectively: Horn meal (= reference), BI 12 (only 2005), BFB, BFB + BFQ. All fertilisers were applied at a rate of 160 kg N ha^{-1} in a strip of 30 cm width into which the plants were transplanted. All treatments were additionally fertilised to an amount of 200 kg K_2O (”Patentkali”, 30:10 K_2SO_4: MgO, Kali & Salz AG, Kassel) and 40 kg P_2O_5 per ha (Rockphosphat ”Hyperphos 31”, Fa. Temag). AUSMA and BFQ were applied each 2 weeks for first 2 months of the growing season (4 times) in a 1 and 4 % solution, respectively, with *250* ml per plant and treatment.

Weekly harvests started in the beginning of August and lasted until mid October. Fruits with late blight lesions or other disease symptoms were also harvested and weighed separately. Yield was determined for each plant.

3.2.3.2. Poly tunnel trial 2007

The effects of the organic fertilizer BFB and a combined treatment of BFB and the biostimulant BFQ were compared to reference fertilisation with horn meal in a commercial type of setup with container grown tomatoes of the cultivar Philovita in a ploy tunnel.

Three four week old plants were transplanted in plastic pots of 90 l capacity in four replicates on May 16th 2007. Soil was underground loam from soil profile below 90 cm, which was low in nutrient content to which 10 % yard waste compost (73.1 % DM, 433, 107, 1700 and 12000 mg kg^{-1} DM, NO_3-N, NH_4-N, P_2O_5, and K_2O, respectively) was added.

BFB and Horn meal were applied one day before transplanting at 3.0:1.2:2.9 g NPK $plant^{-1}$ fertilization level, respectively. Since fertilizers were lacking in phosphorous and potassium, extra rock phosphate (27 % P_2O_5) and crude potassium – magnesia (”Patentkali” 30 % K_2O, 10 % MgO) were added to the soil in order to obtain the desired fertilization level. BFQ was applied 6 times to the plant basis at a concentration of 2 % in 100 ml aqueous solution per plant and application. Application time of BFQ was scheduled at 14 day intervals with the first application on June 5th and ending at August 14th. Harvest started on July 17th and ended after 10 harvests on October 17th.

3.2.3.3. *P. infestans* inoculation experiment with detached tomato leaves

In a separate experiment, about five week old plants of cultivar Matina were used. The plants were grown in a greenhouse (13 cm diameter pots) in soil from an organic field and fertilised to equal nutrient levels with organic fertiliser horn meal and BFB at transplanting. The experiment was repeated 3 times with four replications each time. Greenhouse temperature was 23°C and 18°C during day and night, respectively. From seven days after transplanting, plants were watered weekly four times with 50 ml of an aqueous solution of BFQ in 4 % concentration; control plants were given water only. Leaves for inoculation were detached one month after transplanting. Two inoculation experiments were also conducted with detached tomato leaves of adult plants of cultivar Philovita from the described poly tunnel trial. Inoculation of Philovita leaves was done on July 26th 2007 and August 8th 2007.

Depending on the test, either *P. infestans* isolate 101 or 108, collected locally in 2004; both with broad-spectrum virulence on tomatoes were used. Actively growing colonies of *P. infestans* were transferred into 1.5 % pea agar (liquid of 125 g boiled peas l^{-1} agar) and incubated in the dark at 18°C for about 21 days before use for inoculation. The two first lateral leaflets of the youngest completely developed leaves were detached and placed lower side up in plastic trays lined with wet fleece and filter paper and covered with plexi glass. Two levels of inoculum were applied to each leaflet with a 20 µl drop of a solution of $5*10^4$ and $10*10^4$ sporangia ml^{-1} respectively. Trays were kept in the dark for 24 h at 17 °C. After 24 h, a 16 h light/ 8 h dark cycle was maintained and leaves were sprayed with sterile demineralised water every 2 days. Percent diseased leaf area was assessed daily from day 5 to 8.

3.2.4. Potato trials

Plot size in all potato trials was 3.5 m (6 rows) wide by 8 m long. Three rows were used for sequential harvests; the remaining rows were used for the final harvest. Within a row, the planting distance was 33 cm i.e. a plant density of 40.000 plants ha^{-1}.

Cultivars Salome (Fa. Norika, Groß Lüsewitz) and Velox (SAKA RAGIS Pflanzenzucht, Hamburg), both belonging to the early maturing group, were used in 2004. They mainly differed in their tuberisation characteristics. Salome is able to produce a higher amount of stems and tubers than Velox, while Velox is able to produce a higher number of marketable size tubers earlier in the season than Salome. The cultivar Nicola was used in the experiments in 2005 and 2006. Nicola belongs to the ”middle early” maturity group with an early tuber bulking behaviour and a mid to high susceptibility to late blight (Bundessortenamt, 2004).

Weeds were controlled by harrowing and hilling. Colorado potato beetle (*Leptinotarsa decemlineata*) was controlled using 2.5 l ha^{-1} Neem extract (Neem Azal -T/S, Trifolio-M GmbH, Lahnau, Germany) in a 500 l ha^{-1} spraying mixture. All agronomical measures (e.g. crop protection and fertilization) carried out in the field trials were in accordance with the EU regulations for organic farming. Three sequential harvests were conducted at 75, 85 and 95 days after planting (dap) to determine the yield formation dynamics, the haulm biomass development and the nitrogen uptake dynamics of the crop at different growth stages, respectively. For each sequential harvest one row (20 plants) was harvested. The remaining 3 rows (60 plants) were used for the final harvest. For the sequential harvests, haulms were cut directly above the ground. The fresh matter weight was determined immediately in the field. The tuber yields were graded into cultivar specific marketable yield size categories. Samples were taken to conduct further analyses, respectively.

3.2.4.1. Design and treatments 2004

The experiment was laid out as a three factorial randomized complete block design with four replicates. Factor A was the fertiliser treatment, factor B the biostimulant spraying regime and factor C the cultivar. Fertiliser treatments were BFE, BI12 and as reference a horn meal fertiliser with a nutrient input of 75 kg N, 40 kg P_2O_5 and 40 kg K_20 ha^{-1}, respectively. In addition, a treatment without nitrogen input (”Zero”) was included. A commercial fertiliser permitted for organic farming was applied with 40 kg K_20 (Patentkali, 30:10 K_2SO_4: MgO) and 40 kg P_2O_5 per ha (Rockphosphat ”Hyperphos 31”) to all treatments except to the *BioFeed-Ecomix* plot. All fertilisers were applied in the centre of the row before planting.

As liquid leaf application treatment with AUSMA (40 %; 2, 5 l ha^{-1} in 250 l H_2O ha^{-1}) and a water equivalent control were used. AUSMA was applied two times; at 18.05. 21 days after crop emergence and at the beginning of flowering on 19.06.

3.2.4.2. Design and treatments 2005

The experiment was laid out as a three factorial split-plot trial in four replicates. Factor A was the fertiliser treatment, factor B the N-supply level and factor C the biostimulant spraying regime. Potatoes were planted after pre-crop oat (*Avena sativa L. cultivar Jumbo*). Oat was the third crop after grass/clover ley resulting in a nitrogen content of the soil of

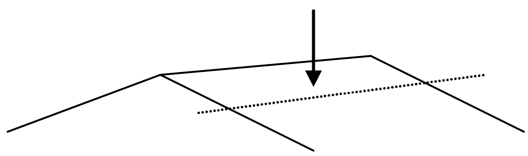
about 50 kg N-min ha^{-1} (0-60 cm) at the end of April (planting date). Fertilisers BFB and BI 12 were applied at nitrogen levels of 75 and 150 kg N ha^{-1}, respectively. Treatments were compared to a control (”Zero”) without additional nitrogen. Fertilisers were applied as a strip application directly into the row close to the seed tubers. All treatments were fertilised with 40 kg P and 80 kg K ha^{-1} (equivalent to the amount of P and K supplied with BFB 150 kg N ha^{-}) by commercial fertilisers permitted for organic farming (see above).
BFQ was sprayed in an aqueous solution of 1: 25 with 500 l ha^{-1} per treatment. Plants were treated weekly four times starting three weeks after crop emergence (June 6th) until flowering (July 4th).

3.2.4.3. Design and treatments 2006

Two separate experiments were carried out in 2006 to test effects of the fertilisers and the biostimulant. The fertiliser trial was a two factorial split plot design with four replicates. Factor A was the fertiliser treatment, factor B the fertiliser placement. Fertilisers BFB and BI 12 and a horn meal- control were applied at nitrogen level of 40 kg N ha^{-1}, as broadcast and strip application. Additional fertilisation with P and K was conducted as in previous years. Winter wheat (*Tritcum aestivum L. cultivar Capo; WW*) was pre crop which was grown after a grass clover ley. Mineralization of soil N was delayed due to a long winter period. Prior to planting, nitrogen content of the soil was about 45 kg N-min ha^{-1} but it increased continuously in the unfertilised plots to 91 kg N-min ha^{-1} at crop emergence (0-60 cm soil profile).
In the second trial for testing the biostimulant BFQ, the pre-crop was alfalfa grass/clover ley (*Medicago sativa L., Trifolium repens L., T. pratense L., Lolium perenne L., Festuca pratensis Huds*.) (75 kg N-min ha^{-1} in 0-60 cm soil profile at planting date). No fertilisers were applied. The experiment was a randomized complete block design with four replicates. Applications were done at the same amounts and growth stages as in 2005. No sequential harvests were conducted in that trial.

3.2.5. Soil and plant sampling

In potato plots, samples for N-min were taken in the soil profiles 0-30 and 30-60 cm from the middle of the trailing edge of the potato ridge (see sketch)



according to standard assessment methods (Scharf and Wehrmann 1976; Schinner et al. 1998). First samples were taken prior to planting. Further samples were taken during the vegetation at crop emergence, beginning and end of flowering in potatoes. In tomato plots soil samples were taken monthly from early June to early October between the plants of each plot in the profiles 0-30 and 30-60 cm, respectively.

3.2.6. Disease assessments

Late blight assessments started when first spots were seen in the field and continued regularly twice a week on four sections per potato plot and on four preselected tomato plants per plot. Percent diseased leaf area was estimated, following the key of James et al. (1971). The assessments ended when crops were destroyed due to disease and/or maturity.
Black scurf (*Rhizoctonia solani*) and common scab *(Streptomyces scabies*) of potatoes were assessed on 100 tubers per plot. Tubers were divided into six or seven infection classes according to the EPPO – standard PP 1/32 (2) (EPPO, 2000s (Table 3. 2).

Table 3. 2: Assessment scheme of black scurf and common scab on potato tubers (James & Mc Kenzie, 1972)

Class	% infested tuber surface	
	Black scurf	Common scab
1	0	0
2	1	1-10
3	5	11-20
4	10	21-30
5	15	31-40
6	> 15	41-50
7		>50

3.2.7. Laboratory analyses

Mineralized nitrogen (N-N min) was determined for soil layers 0-30 and 30-60 cm using 1 % K_2SO_4 as an extractant according to the method described by Hoffmann (1991). The concentrations of NO_3-N were converted to quantities per ha using bulk densities of 1.43, and 1.50 g cm^{-3} for the 0-30 and 30-60 cm horizons, respectively. Soil bulk densities were taken from a soil survey done by Brandt et al. (2001).
Dry matter (DM) of the haulms from sequential harvests was determined from a sub sample of around 500 g from all sub-plots by weighing before and after drying at 80 °C for 48 h. Samples were ground (0.5 mm) with a Pulverisette No. 19 laboratory cutting mill (Fritsch, Idar-Oberstein, Germany) and sub-samples of 1 g (four decimal places) dry-ashed in a Heraeus Thermicon T muffle oven (Elementar Analysesysteme, Hanau, Germany) at 550 °C for 8 h and, before weighing, kept inside a desiccator to cool down. Subsequently,

HCl (32 %) was added and the solution left overnight. After filling up to 100 ml with distilled H_2O, samples were passed through a 615¼ filter (Macherey and Nagel, Düren, Germany) and placed in 100 ml polyethylene bottles. From these samples, total N % was determined using a Macro N auto-analyser (Elementar Analysesysteme, Hanau, Germany). At each harvest, a sub sample of 20 tubers (size-graded 30-60 mm) per plot was cut into cubes of 1 cm^3 with a Dito TRS vegetable cutter (Dito ElectroluxCo., Herborn, Germany) and the DM content determined by weighing before and after drying at 80 °C for 72 hours. Immediately after drying the samples were ground (0.5 mm) and stored in a dry, cool and dark place until further analysis.

Nitrogen contents of haulms and tubers were analyzed at 3 sequential harvests (75, 85 and 95 days after planting) to determine the quantities of nitrogen uptake in kg N ha^{-1} in the different plots. At final harvest only the nitrogen content of the tubers was determined because of previous defoliation.

3.2.8. Data analysis

Cumulative late blight severity was calculated as the area under the disease progress curve (AUDPC) following Kranz (1996):

$$AUDPC = \sum_{i=1}^{n-1} \left(\frac{x_{i+1} + x_i}{2} \right) (t_{i+1} - t_i)$$

$\mathbf{y_i}$ = Percent attacked leaf area, $\mathbf{t_i}$ = Days between assessments, **n** = Amount of assessments

For the tuber diseases, the mean percentage infestation of the tuber surface was calculated before analysis.

N uptake of haulms and tubers was calculated by multiplying N (%) concentration by tuber DM yield and biomass of the haulms, respectively. The ratio of tuber to whole crop N-uptake was calculated at 95 dap. N utilisation efficiency (NUE) denotes the final tuber yield (t FM ha^{-1}) per kg N uptake by the whole crop at 95 dap (on the basis of Huggins & Pan 1993).

Statistical analyses of field trials were done with SPSS (version 13). All percentage values were arc sine transformed before analysing. The *Kolmogorov-Smirnov test* was conducted to analyse the normal distribution. Data were analysed with the GLM procedure with fixed effect models with the treatments and their interactions as main factor, and replicates as random effect. The *Bonferroni-Holm* Test was conducted to separate means with a confidence level of 95 %.

Data of the leaf inoculations were log-transformed and then analysed together using SAS PROC mixed. A two-factorial analysis was done for fertilizer and biostimulant treatments as a main effect, and fertilizer*biostimulant for their interaction. If significant effects were detected, means were compared with Tukey-Kramer with a confidence level of 95 %.

3.3. Results

3.3.1. Climatic conditions and late blight development

The temperatures in 2004 complied with the average temperature, whereas the precipitation was much lower from March to June and much higher in July than usual. Climatic conditions in 2005 were close to the long-term average except for very low precipitation in June. In 2006, the winter was very cold while the summer was very warm with a hot and dry period beginning on June 8th with nearly no precipitation until July 25th (Table 3. 3).

Table 3. 3: Climatic conditions at the experimental site Eichenberg during the seasons 2004, 2005 and 2006 as well as the average conditions of the period 1991-2001 (Source: Mean 1991-2001 calculated by the Department of Forage Production and Grassland Ecology; Data from 2006 and 2007 measured by the Department of Ecological Plant Protection)

Month	Mean air temperature in °C				Precipitation in mm			
	1991-2001	2004	2005	2006	1991-2001	2004	2005	2006
January	1	0.7	2.6	-2.4	49	54	49	21
February	1.3	3.2	-0.2	-0.5	43	42	30	40
March	4.7	4.2	5.2	1.5	56	28	31	56
April	8.1	8.9	9.3	8.1	45	32	31	38
May	12.6	11	12.5	12.7	50	31	56	84
June	15	15	15.6	16.3	69	38	38	28
July	17.5	15.8	18	21.2	75	98	62	59
August	17.4	18.4	15.7	15.6	62	65	72	73
September	13.1	15.9	14.9	16.9	61	0	28	18

3.3.2. Tomato trials

3.3.2.1. Soil nitrogen dynamics

There were no significant differences between the fertilising regimes within years and sampling dates in soil profiles 0-30 and 30-60 cm, respectively. Overall plant available soil N (0-60 cm soil profile) followed a similar course in all treatments in 2005 and 2006. (Figure 3. 1). However, soil N- supply differed between the years especially at the first sampling date (beginning of June) when plant available N was about 40 kg ha^{-1} higher in 2006 than in 2005, respectively. Later in season differences became smaller (Figure 3. 1). Most of the mineralised nitrogen was NO_3-N and only on the first sampling dates in both years noteworthy amounts of soil NH_4- N were found. In 2005, soil NH_4-N content in the soil profile 0-60 cm ranged from 12 – 20 kg ha^{-1} and was lowest in the horn meal and highest in the BFB treatment. In 2006, differences between treatments were even smaller and contents ranged between 18 – 20 kg ha^{-1}. At all other sampling dates soil NH_4- N contents were below 5 kg ha^{-1}. Hence, data are shown as total mineralised N. Overall, standard deviations within soil profiles at all sampling dates in both years were quite high (Figure 3. 1).

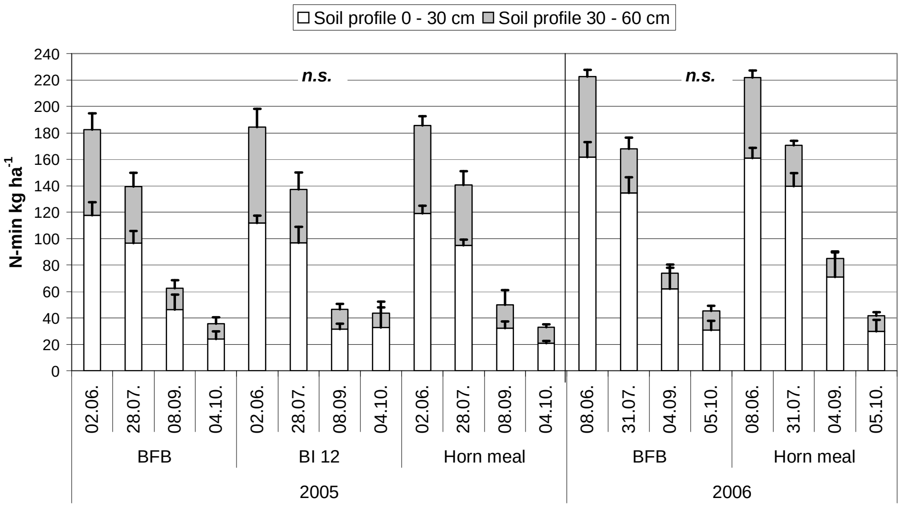


Figure 3. 1: Soil nitrogen dynamics (kg N-min ha^{-1}) in tomato plots in 2005 and 2006 of soil profiles 0-30 cm (white bars) and 30-60 cm (grey bars) fertilised with BF-Basis and BioIlsa12,5 Export (only2005) in comparison with the horn meal reference (N-fertilisation level = 160 kg N ha^{-1}) from beginning of June to beginning of October, respectively. Error bars represent standard deviations for soil profiles, respectively.

3.3.2.2. Marketable tomato yield and late blight on fruits

The marketable yield of Matina varied strongly between the years. In 2006, the mean was 2219 g $plant^{-1}$. In 2005, marketable yield per plant was 1190 g lower because of much higher late blight disease pressure (Figure 3. 2 and Figure 3. 3). The differences in yields in 2006 and 2007 for Philovita were due to the different growing systems. The fertilisers BFB and BI 12 alone resulted in slightly higher marketable yields of Matina in 2005 albeit not statistically significant in comparison to horn meal (Figure 3. 2.). The highest marketable yields were achieved when the fertiliser BFB was combined with either of the two biostimulants AUSMA or BFQ in 2005 or with BFQ in 2006 and 2007 (Figure 3. 2. and Figure 3. 4.) The yield increases were mainly due to a higher share of healthy fruits for

Matina in 2005 and 2006 and an increased number of fruits (between 13 and 27 more fruits per plant) for cultivar Matina in 2006 and Philovita in 2006 and 2007 (Figure 3. 3 and Figure 3. 5).

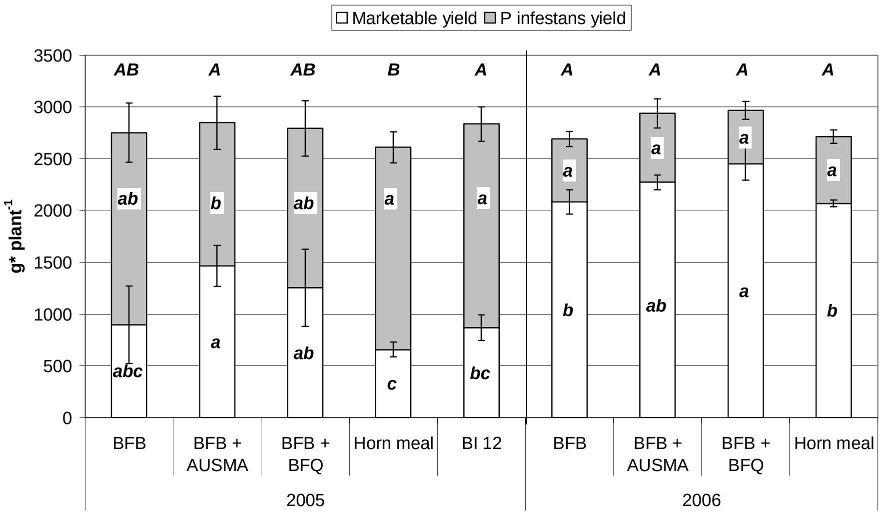


Figure 3. 2: Marketable fruit yield (white bars) and weight of fruits infected with late blight (grey bars) of tomato cultivar Matina in 2005 and 2006. Plants were fertilised with BF-Basis (BFB) and BioIlsa12,5 Export (BI 12) (only 2005) combined with biostimulants BF-Quality (BFQ) and AUSMA compared to a reference fertiliser treatment with horn meal (N-fertilisation level = 160 kg N ha^{-1}). Different upper case letters show significant differences in total fruit yield and different lower case letters significant differences in marketable and infected fruit yield between the treatments within year, respectively. Error bars represent standard deviations for marketable and late blight infected fruit yield, respectively.

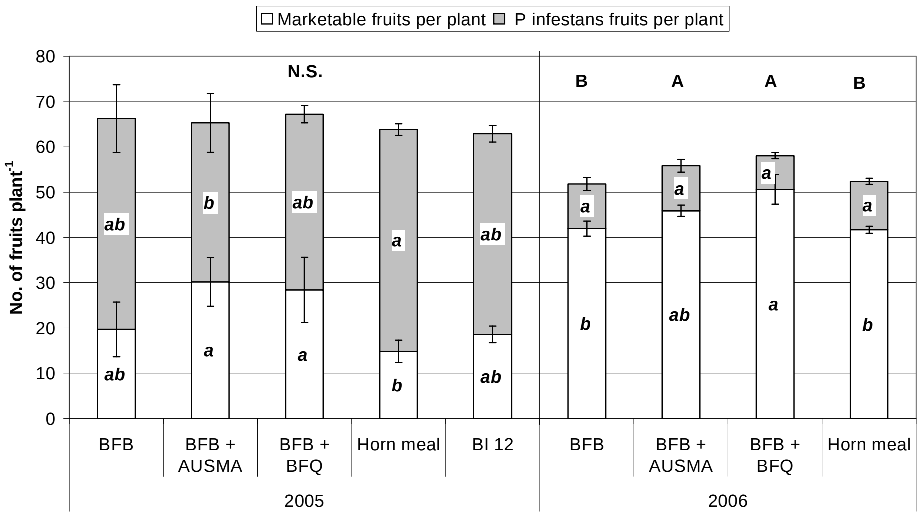


Figure 3. 3: Amount of marketable fruits (white bars) and fruits infected with late blight (grey bars) of tomato cultivar Matina in 2005 and 2006. Plants were fertilised with BF-Basis (BFB) and BioIlsa12,5 Export (BI 12) (only 2005) combined with biostimulants BF-Quality (BFQ) and AUSMA compared to a reference fertiliser treatment with horn meal (N-fertilisation level = 160 kg N ha^{-1}). Different upper case letters show significant differences in total fruit number and different lower case letters significant differences in marketable and infected fruit number between the treatments within year, respectively. Error bars represent standard deviations for marketable fruits and late blight infected fruits, respectively.

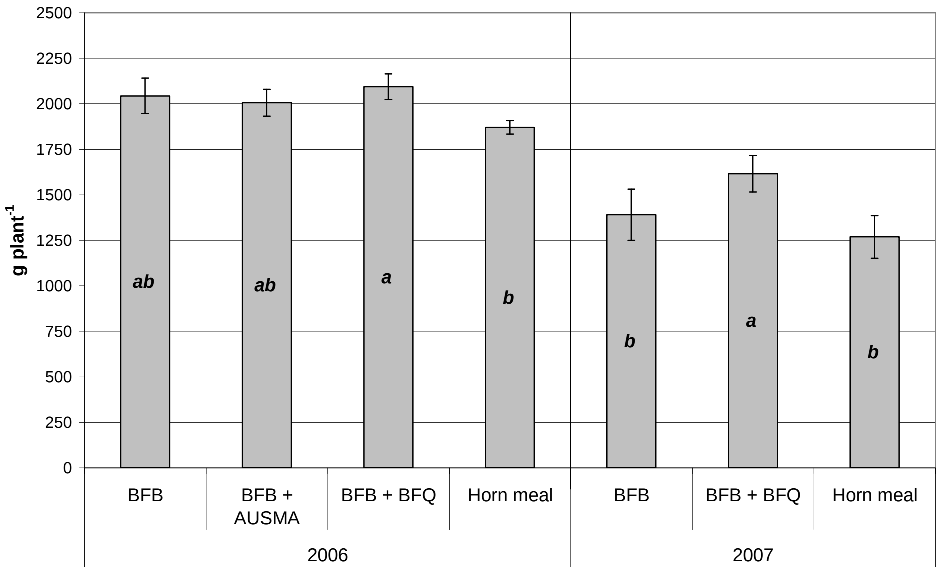


Figure 3. 4: Marketable fruit yield of tomato cultivar Philovita fertilised with BF-Basis and BF-Basis combined with biostimulants AUSMA (only 2006) and BF-Quality in comparison with the horn meal reference grown in open field 2006 (N-fertilisation = 160 kg N ha^{-1}) and in poly tunnel 2007 (3 plants pot N-fertilisation =, 3 g N $plant^{-1}$), respectively. Different letters show significant differences between the treatments within year (Bonferroni $p \leq 0.05$) and error bars represent standard deviations, respectively.

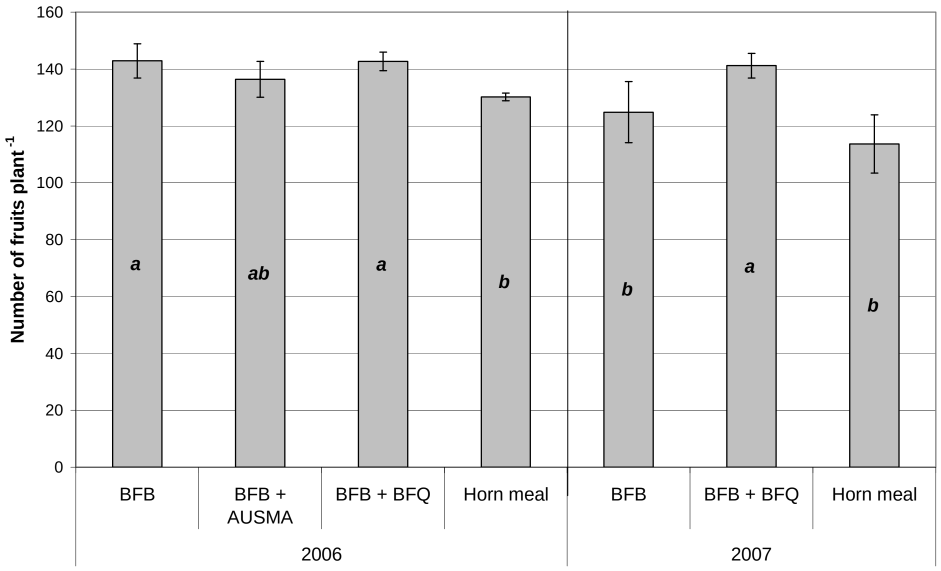


Figure 3. 5: Amount of marketable fruits of tomato cultivar Philovita fertilised with BF-Basis and BF-Basis combined with biostimulants AUSMA (only 2006) and BF-Quality in comparison with the horn meal reference grown in open field 2006 (N-fertilisation = 160 kg N ha^{-1}) and in poly tunnel 2007 (3 plants pot N-fertilisation =, 3 g N $plant^{-1}$), respectively. Different letters show significant differences between the treatments within years (Bonferroni $p \leq 0.05$) and error bars represent standard deviations, respectively.

3.3.2.3. Effects on tomato foliar late blight

Late blight infection of tomato leaves was only in 2005 of significance. In 2006, foliar late blight severity was very low as weather conditions were unfavourable for the disease and leaves died at mid September due to infestation with powdery mildew (*Oidium lycopersici*) and tomato rust mite (*Aculops lycopersici*). No late blight could be observed in 2007 when the tolerant cultivar Philovita was grown in the poly tunnel.

In 2005, late blight started later and was less severe in all BFP treatments in comparison to the horn meal fertilised reference. The mildest infection course was observed in the treatment BFB + AUSMA. Infection started about 10 days later and remained less severe until mid September, compared to the reference (Figure 3. 6). Consequently, all BFP treatments reduced the cumulative disease severity, i.e. the *Area Under Disease Progress Curve* (AUDPC) significantly compared to the horn meal -reference. Reductions ranged from 35 % (BFB+ AUSMA) to 17 % (BF-Basis, BF-Basis + -BF-Quality) compared to the reference (Figure 3. 7).

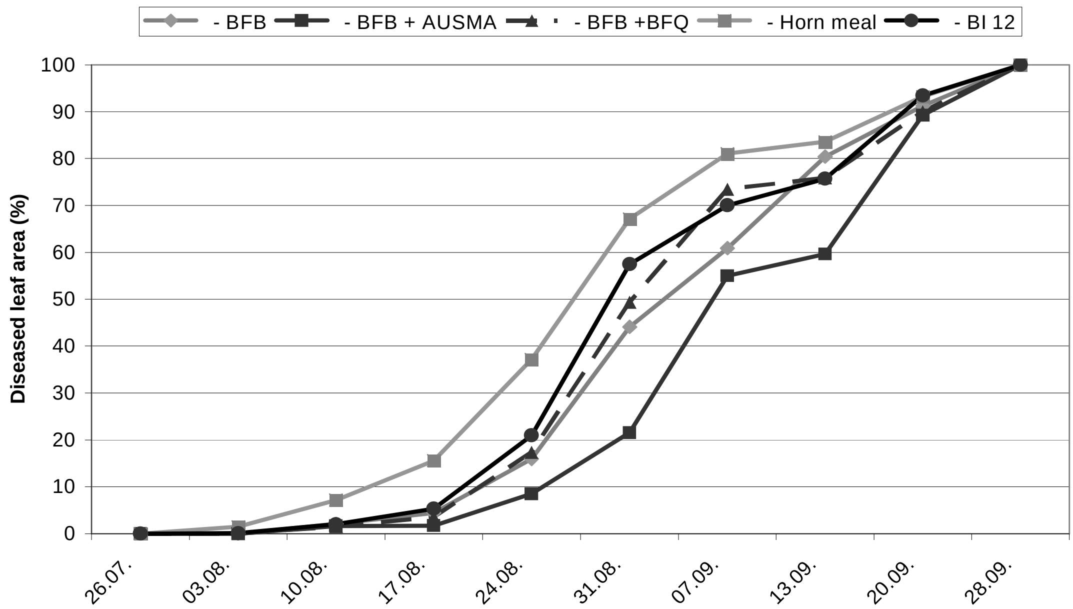


Figure 3. 6: Disease progress of *Phytophthora infestans* (% attacked leaf area) on cultivar Matina in 2005 when treated with BF-Basis, BioIlsa 12,5 Export and BF-Basis combined with biostimulants AUSMA and BF-Quality in comparison to a horn meal fertilised reference, (N-fertilisation level = 160 kg $N*ha^{-1}$).

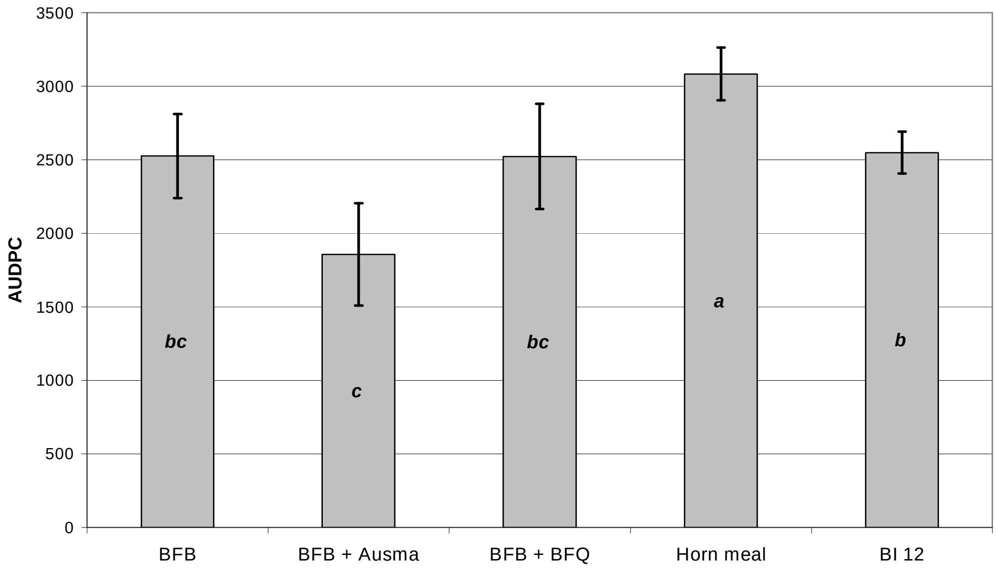


Figure 3. 7: Area under disease progress curve (AUDPC) of the leaf infection course with *Phytophthora infestans* of cultivar Matina in 2005 treated with BF-Basis, BioIlsa 12,5 Export and BF-Basis combined with biostimulants AUSMA and BF-Quality in comparison with the horn meal reference (N-fertilisation level = 160 kg N ha^{-1}). Different letters show significant differences between the treatments. Error bars represent standard deviations

3.3.2.4. Effects of fertilisers and biostimulants on the susceptibility of tomatoes to late blight in detached leaf tests

When grown under controlled conditions in a greenhouse biostimulants AUSMA and BFQ significantly reduced plant susceptibility in young tomato plants of cultivar Matina compared to the water control in 2 out of 3 experiments. Reduction in disease by biostimulant application was not statistically significant in experiment 2 when overall disease severity was significantly lower than in both other experiments. However, mean disease reduction of AUSMA and BFQ on detached leaves of cultivar Matina was relatively similar by 37, 20 and 24 % in experiments 1, 2 and 3, respectively (Fig. 3.8). In treatments amended with BFB, no difference in disease could be observed compared to soil amended with horn meal. There was also no interaction between biostimulants and soil amendments.

Detached leaves of adult plants of Philovita which were taken from the 2007 poly tunnel trial were significantly more resistant against *P. infestans* when fertilised with BFB than when fertilised with horn meal independent of inoculum density. This effect was significantly enhanced by the use of BFQ. The combined use of BFB and BFQ reduced infection by 57 and 62 % across the two sampling dates compared to the control with horn meal and water treatment (Fig. 3.9).

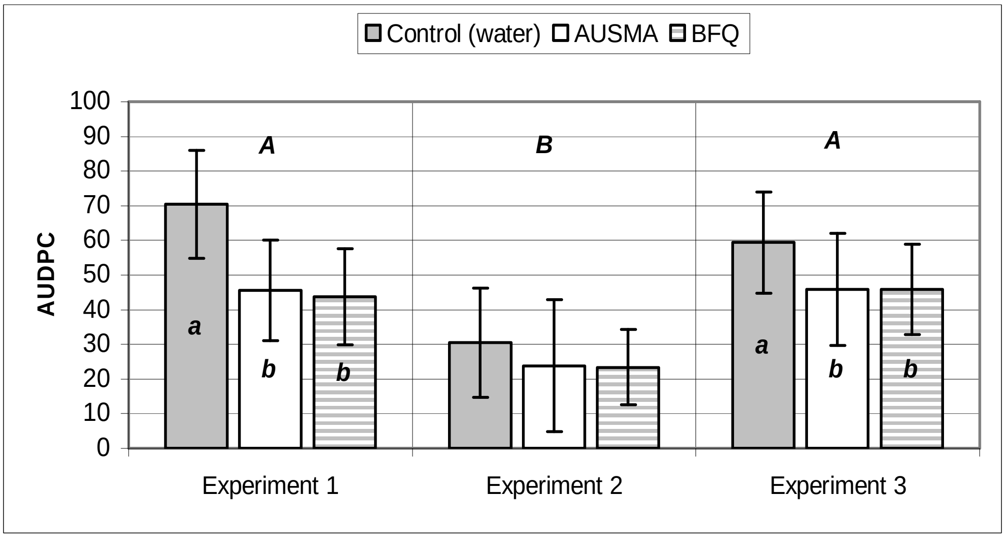


Figure 3. 8: Area Under Disease Progress Curve of *P. infestans* of three experiments on detached leaves after inoculation with aggressive *P. infestans* strains (101& 108 locally collected) of tomato cultivar Matina grown under glasshouse condition and treated with the biostimulants AUSMA and Biofeed Quality compared to a water control (all poured to plant basis) . Significant differences among experiments are marked with different upper case letters; significant differences among treatments are marked with different lower case letters (Tukey p≤0.05, t- LSD, PROC GLM, SAS).

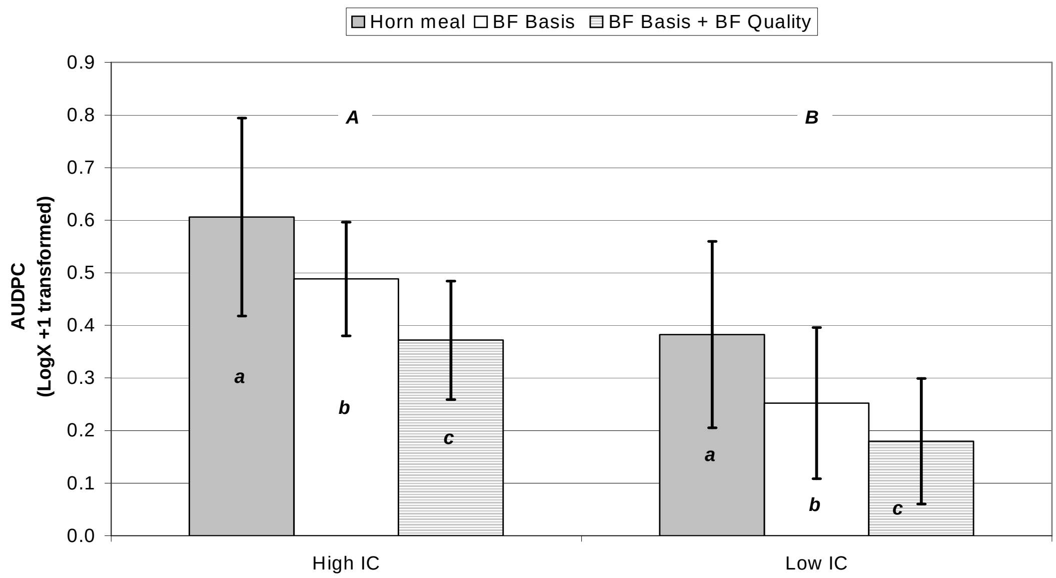


Figure 3. 9: Log-transformed Area Under Disease Progress Curve of *P. infestans* on detached leaves after inoculation in high and low inoculation densities (20µl drop of a solution of $10*10^4$ and $5*10^4$ sporangia ml^{-1} respectively) with aggressive *P. infestans* strains (101& 108 locally collected) on adult plants of tomato cultivar Philovita treated with fertilisers horn meal (reference) compared to Biofeed Basis and Quality of. The presented value is the mean of 2 sampling dates. Errors bars represent standard deviation. Significant differences among inoculation densities are marked with different upper case letters; significant differences among treatments are marked with different lower case letters (Tukey p≤0.05, t- LSD, PROC GLM, SAS). Mean separation was done by Tukey- Kramer (p≤0.05) grouping with the log-transformed data.

3.3.3. Potato trials

3.3.3.1. Late blight development

In 2004 and 2005, late blight in potatoes was first seen around July10th. The disease developed relatively fast in 2004 and the nearly mature crop died within ten days. In contrast, in 2005 disease developed slowly until the first of August. Afterwards, it increased quickly and all plants died within two weeks. In 2006, the first late blight was observed at the end of July and disease increased continuously until crop death at the end of August. Neither the biostimulant BFQ nor fertilisation levels affected AUDPC in any of the trials in all three years.

3.3.3.2. Soil nitrogen dynamics

Overall, there were no significant differences among treatments in soil nitrogen levels in 2004. However, mean N-mineralization in plots fertilised with BI 12 was somewhat delayed compared to the ones fertilised with BFE and horn meal. In the beginning of May (crop emergence) mean soil N-min in plots fertilised with BI 12 was about 20 kg ha^{-1} lower but by mid June (begin of blossom) soil N-min was about 30 kg ha^{-1} higher, compared to horn meal and BFE. Later in the season soil N-min was almost the same in all treatments (Figure 3. 11).

In the 2005 trial, plant available soil N at a fertilisation level of 150 kg N ha^{-1} was significantly higher than at 75 and 0 kg N ha^{-1} at all sampling dates (Figure 3. 11). The highest differences in plant available soil N (soil profile 0-60cm) were found in the middle of June. From May to mid July, differences decreased from +108 and +112 to + 31 and +38 kg N ha^{-1}, respectively (Figure 3. 11). The differences between plots fertilised with 75kg N ha^{-1} and unfertilised plots were also significant at all sampling dates with the highest differences at crop emergence and tuber formation (+ 32 and + 29kg N ha^{-1}, respectively) (Figure 3. 11). Differences between the fertilisers in N-min N were not significant within fertilisation level.

In the high fertilisation plots nitrogen peaked in the middle to end of June while it peaked in the beginning of June in the plots that had received 75 kg N ha^{-1} or none. Starting mid June, differences in BBCH stages became visible between the fertilisation levels when potatoes with high fertilisation started flowering (BBCH60) whereas potatoes with middle and no fertilisation were already at mid and end flowering, respectively. In 2006, when strip and broadcast fertilisation of 40 kg N ha^{-1} were compared, across fertilisers about 15kg ha^{-1} more N remained in the topsoil with strip application than with the broadcast application directly after crop emergence (Figure 3. 12).

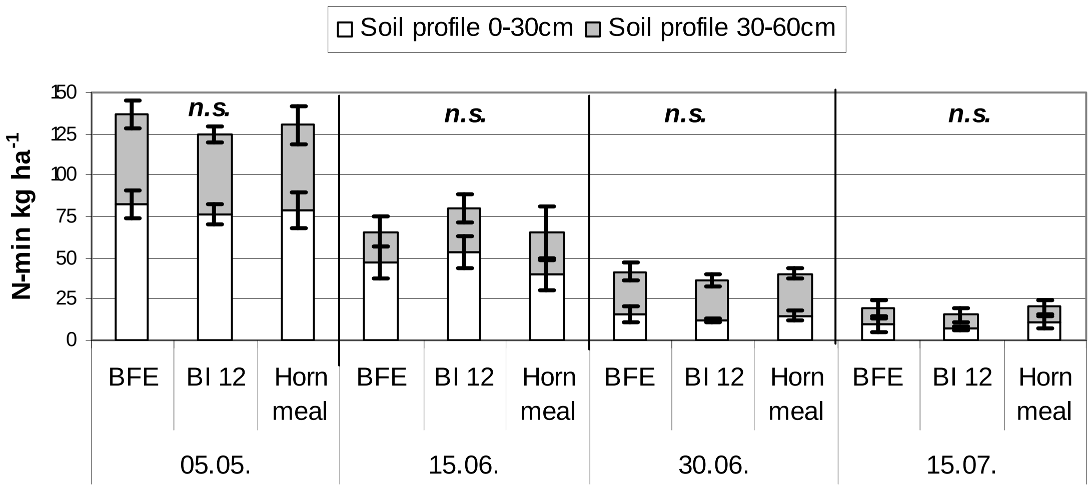


Figure 3. 10: Soil nitrogen dynamics (kg N-min ha^{-1}) in 2004 in potato plots treated with organic fertilisers Biofeed Ecomix (BFE) ,BioIlsa 12,5 Export (BI 12) and horn meal reference at N-supply levels 75 kg N ha^{-1} in soil profiles of 0-30 (white bars) and 30-60 cm (white bars).
Error bars represent standard deviations. Different letters indicate significant differences at sampling dates and soil profiles, respectively (Bonferroni p≤0.05)

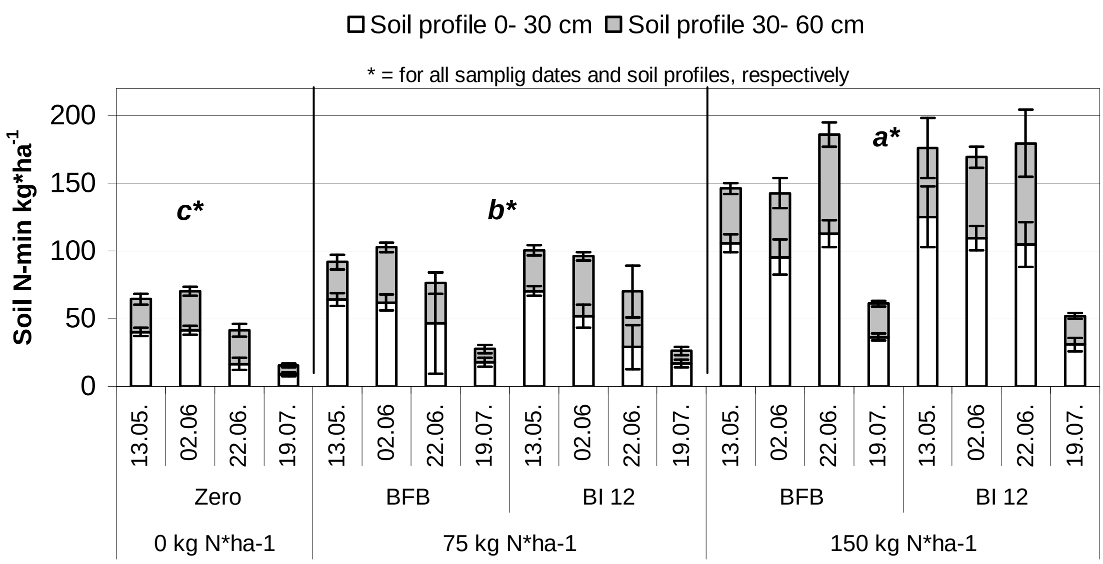


Figure 3. 11: Soil nitrogen dynamics (kg N-min ha^{-1}) in 2005 in potato plots treated with fertilisers Biofeed Basis (BFB) and BioIlsa 12,5 Export (BI 12) at two N-supply levels (75 a. 150 kg N ha^{-1}) and a control (0 kg N ha^{-1}) in soil profiles of 0-30 (white bars) and 30-60 cm (grey bars).
Error bars represent standard deviations. Different letters indicate significant differences at sampling dates and soil profiles, respectively (Bonferroni p≤0.05)

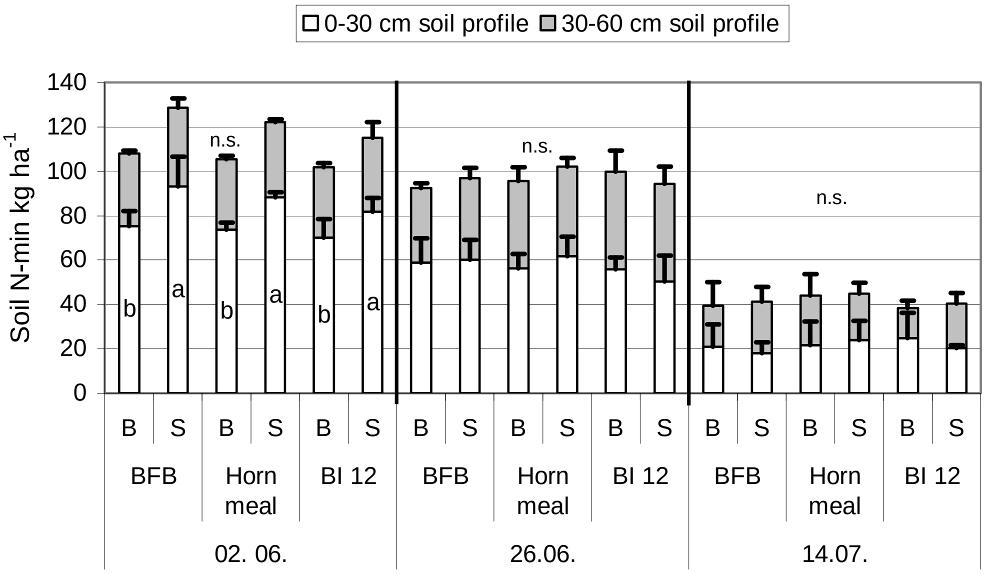


Figure 3. 12: Soil N-min N (kg N-min ha^{-1}) in soil profiles of 0-30 (white bars) and 30-60 cm (grey bars) in potatoes at BBCH stages 12, 39 and 69. Potatoes were fertilised with 40 kg N ha^{-1} by application of organic fertilisers Biofeed Basis (BFB), BioIlsa 12,5 Export (BI 12) and the reference fertilisation horn meal as strip (S) and broadcast (B) application, respectively. Error bars represent standard deviations. Different letters indicate significant differences between strip and broadcast application within soil profile (Bonferroni $p \leq 0.05$)

3.3.3.3. Potato crop N uptake

In 2004 whole crop nitrogen uptake (CNU) of cultivar Salome was higher at 75 and 95 days after planting (dap) than for cultivar Velox. There were no significant differences between the fertiliser treatments within the cultivars at both dates.

In 2005, by late June (75 dap) and mid July (95 dap) CNU was by +30 to +38 and +61 to 69 kg N ha^{-1} higher with 75 and 150 kg N ha^{-1}, respectively, compared to the unfertilised treatments ($p = 0.000$). Increased CNUs were due to higher haulm and tuber mass as well as higher haulm N contents with higher N-supply.

In the 2006 trial, significantly higher amounts of N were taken up by haulms and tubers with strip application compared with broadcast application, resulting in a higher CNU of 9.91 kg N ha^{-1} by mid July (Table 3. 4).

The impacts of the fertilisers on the CNU differed among years. In 2004, horn meal increased mean CNU at 95 dap with cultivar Salome by 4.54 and 5.62 kg N ha^{-1} compared to BI 12 and BFE, respectively. This was not statistically significant, however. In 2005, differences were again not significant but BI 12 had a higher CNU (across fertilisation

levels) of 5.36 and 3.78 kg N ha^{-1} than BFB at 75 and 95 dap, respectively. In 2006, at 95 dap the highest CNU was observed with horn meal. It was significantly different from BI 12 with the lowest CNU (5.36kgN ha^{-1}). CNU with BFB was 2.55 kg N ha^{-1} lower than with horn meal but not significantly different from the other fertilisers (Table 3. 4).
The biostimulants AUSMA (2004) and BFQ (2005) had no significant effects on plant nitrogen uptake. However, at 75 dap BFQ increased mean CNU by 7.76 kg N ha^{-1} whereas at 95 dap no differences were found compared to the control (Table 3. 4).

3.3.3.4. N use efficiency

In 2004, nitrogen utilization efficiency (NUE) was significantly higher with BFE compared to horn meal for cultivar Salome, but not for cultivar Velox. NUE with BI 12 was only slightly higher for both cultivars compared to horn meal. Yield increase per kg N-input (YIN) was higher with BI 12 and BFE than with horn meal for both cultivars. However, due to high standard deviations these differences were not statistically significant. The biostimulant AUSMA had no significant effect on NUE nor YIN of both cultivars, however, with AUSMA mean NUE and YIN increased for cultivar Salome by 0.01 and 16.53 kg and decreased for Velox by 0.01 and 3.59 kg, respectively (Table 3.5).
Fertilisation level and biostimulant treatment both affected NUE in 2005. At 75 kg ha^{-1} N input NUE (0.34) was significantly higher than at 150 kg ha^{-1} N input (NUE = 0.28) (Table 3. 4). Across fertilisation levels NUE was significantly higher (+0.03) when plots were sprayed with BFQ compared to the water control (Table 3. 4). The YIN was also strongly affected by fertilisation level. When fertilised with 75 kg ha^{-1} YIN was more than double than when N-input was 150 kg ha^{-1}. While differences between the two fertilisers were negligible (Table 3.4), treatment with BFQ significantly increased YIN across fertilisers and N-input levels compared to the water treatment (Table 3.5)
In 2006, NUE was significantly lower with horn meal fertiliser (0.28) than when fertilised with BI 12 (0.30), whereas BFB (0.29) differed not significantly from both. Moreover, YIN was also significantly higher with BI 12 and BFB (+ 13.14 and + 11,79 kg, respectively) compared to horn meal (Table 3. 4). Broadcast fertiliser application increased NUE and especially YIN significantly compared to strip application (Table 3. 4)

Table 3. 4: Crop N-uptake (haulm & tuber) at 75 and 95 dap, and N – utilization efficiency (Final yield t ha^{-1} / N-uptake 95 dap), and kg yield at main harvest per kg N input of potatoes fertilised with various organic fertilisers at various N-input levels 2004, 2005 and 2006. Strip and broadcast applications were compared in 2006.

Year / Cultivar	Product	N-input level kg ha^{-1}	Fertiliser placement	75 dap Crop N-uptake kg*ha^{-1}	95 dap Crop N-uptake kg*ha^{-1}	N-utilisation efficiency	kg yield / kg N-input^{-1} *
2004 Salome	BF- Ecomix	75	strip	68.5 a	92.5 a	0.36 a	100.8 a
	BioIlsa 12,5	75	strip	68.6 a	93.6 a	0.35 ab	89.6 a
	Horn meal	75	strip	67.0 a	98.1 a	0.33 b	80.3 a
			p≤	*0.972*	*0.144*	*0.036*	*0.431*
2004 Velox	BF- Ecomix	75	strip	62.4 a	88.3 a	0.38 a	131.3 a
	BioIlsa 12,5	75	strip	65.4 a	86.4 a	0.40 a	145.3 a
	Horn meal	75	strip	62.3 a	88.1 a	0.38 a	124.6 a
			p≤	*0.369*	*0.823*	*0.287*	*0.134*
2005 Nicola	BF- Basis	75	strip	82.7 b	104.2 b	0.34 a	158.6 a
		150	strip	106.5 a	131.7 a	0.28 b	87.6 b
	BioIlsa 12,5	75	strip	83.4 b	108.3 b	0.33 a	155.9 a
		150	strip	116.5 a	134.7 a	0.27 b	81.8 b
			p≤	*0.000*	*0.000*	*0.000*	*0.000*
2006 Nicola	BF- Basis	40	Across fertiliser placements	92.5 a	136.7 ab	0.29 ab	137.5 a
	BioIlsa 12,5	40		90.0 a	129.8 b	0.30 a	138.9 a
	Horn meal	40		92.1 a	139.5 a	0.28 b	125.7 b
			p≤	*0.434*	*0.049*	*0.026*	*0.018*
	Across fertilisers	40	broadcast	89.0 a	129.2 b	0.29 a	113.2 b
		40	strip	96.4 a	141.5 a	0.28 b	156.7 a
			p≤	*0.496*	*0.001*	*0.072*	*0.000*

.

Different letters within columns indicate significant difference between treatments (Bonferroni-Holm multiple range test (P < 0.05).

Table 3. 5: Crop N-uptake (haulm & tuber) at 75 dap, 95 dap and N utilization efficiency (Final yield t ha^{-1} / N-uptake 95 dap) and kg yield at main harvest per kg input of potatoes (cultivars. Salome and Velox (2004) and Nicola (2005) spayed with biostimulants AUSMA (2004) and Biofeed Quality (2005) compared to water control, respectively.

Year / Cultivar	Product	Application	75 dap Crop N-uptake kg*ha^{-1}	95 dap Crop N-uptake kg*ha^{-1}	N-utilisation efficiency	kg yield / kg N-input^{-1} *
2004 Salome	Ausma	2*2.5l*ha^{-1}	68.6 a	92.4 a	0.36 a	96.6 a
	Water control		66.6 a	91.9 a	0.35 a	80.1 a
		p=	*0.854*	*0.817*	*0.103*	*0.431*
2004 Velox	Ausma	2*2.5l*ha^{-1}	61.0 a	88.2 a	0.38 a	134.2 a
	Water control		64.1 a	88.5 a	0.39 a	137.8 a
		p=	*0.301*	*0.736*	*0.900*	*0.843*
2005 Nicola	BF- Qualtiy	4*10l*ha^{-1}	101.5 a	120.1 a	0.31 a	128.0 a
	Water control		93.7 a	120.4 a	0.30 a	110.9 b
		p=	*0.118*	*0.956*	*0.089*	*0.039*
* = calculated on basis of plots without N-input						

Different letters within columns indicate significant difference between treatments (Bonferroni-Holm multiple range test (P < 0.05).

3.3.3.5. Potato yield dynamics

In 2004, there were no significant differences in yield among the three fertilisers for the cultivars Salome and Velox. When fertilised with BFE, cultivar Salome had a somewhat higher ratio between haulm and tuber DM (RHT) than with the other fertilisers due to slightly lower yields and significantly enhanced haulm mass (data not shown) at 75 and 95 dap (Table 3.6). Biostimulant AUSMA had no effects on yield and crop growth dynamics with both cultivars (Table 3.7).

In 2005, adding 75 and 150 kg N ha^{-1} increased gross yields (GY) significantly by 34 % and 40 % compared with no N-fertilisation respectively (data not shown). However, yield levels did not differ between the two fertilisation levels. Differences in marketable yield (MY) were similar to the GY (Table 3.6) Results for the sequential harvests were the same. However, RHTs were significantly higher at 150 kg N ha^{-1} input than at 75 kg N ha^{-1} due to increased haulm growth. Differences between fertilisers BFB and BI12 were small with slightly higher GY and MY with BFB In 2006, the yields of potatoes fertilised with BFB and BI12 were similar, out yielding the horn meal reference significantly (Table 3. 6). However, absolute differences were small with 0.6-0.7 t ha^{-1} in GY and MY, respectively. Fertiliser treatments differ not significantly in yield development. Fertiliser strip application increased GY, MY significantly compared to broadcast application (+ 4.8 and 3.5 %, respectively) (Table 3. 6). The increased yield potential of fertiliser application directly in the row could also be observed at the sequential harvests by slightly higher yields and a significantly higher RTH (+0.04) at 95 dap.

The effects of biostimulant BFQ on yield differed between the years. In 2005, the liquid treatment with BFQ resulted in significantly higher GY and MY (+1.94 and +1.76 t ha^{-1}, respectively) and RHT (+0.03) at 95 dap across all N-levels compared to the control. In 2006, no effects on GY and MY were achieved by spraying with BFQ (Table 3.7).

Table 3. 6: Gross yield and ratio haulm/tuber dry matter (DM) at 75 dap, 95 dap and gross and marketable yield at main harvest of potatoes (cultivars Salome and Velox (2004) and Nicola (2005 and ´2006) fertilised with Biofeed Ecomix (2004) Biofeed Basis (2005 and ´2006), BioIlsa 12,5 Export and a horn meal reference (2004/06) at N-input levels 40 (2006), 75 (2004 and 2005) and 150 (2005) kg ha^{-1} applied in a strip (2004-06) and broadcast (2006).

Year / Cultivar	Product	N-input level kg ha^{-1}	Fertiliser placement	75 dap		95 dap		Main harvest	
				Gross yield t*ha^{-1}	Ratio haulm/tuber DM	Gross yield t*ha^{-1}	Ratio haulm/tuber DM	Gross yield t*ha^{-1}	Marketable yield t*ha^{-1} *
2004 Salome	BF- Ecomix	75	strip	14.42 a	0.46 a	24.71 a	0.20 a	33.71 a	30.54 a
	BioIlsa 12,5	75	strip	15.69 a	0.39 ab	25.48 a	0.17 b	32.87 a	29.95 a
	Horn meal	75	strip	15.60 a	0.36 b	25.54 a	0.17 ab	32.17 a	29.19 a
			p≤	*0.447*	*0.027*	*0.720*	*0.031*	*0.431*	*0.470*
2004 Velox	BF- Ecomix	75	strip	17.30 a	0.33 a	24.80 a	0.19 a	33.47 a	32.62 a
	BioIlsa 12,5	75	strip	18.55 a	0.30 a	23.79 a	0.20 a	34.52 a	33.56 a
	Horn meal	75	strip	17.10 a	0.31 a	25.03 a	0.19 a	32.98 a	31.52 a
			p≤	*0.203*	*0.330*	*0.700*	*0.890*	*0.143*	*0.167*
2005 Nicola	BF- Basis	75	strip	16.03 a	0.50 b	30.01 a	0.24 b	35.70 a	34.05 a
		150	strip	14.11 a	0.74 a	30.70 a	0.30 a	36.93 a	35.49 a
	BioIlsa 12,5	75	strip	15.09 a	0.60 b	31.73 a	0.20 b	35.49 a	33.42 a
		150	strip	14.98 a	0.76 a	31.38 a	0.29 a	36.06 a	34.31 a
			p≤	*0.414*	*0.000*	*0.716*	*0.000*	*0.477*	*0.199*
2006 Nicola	BF- Basis	40	Across fertiliser placements	10.53 a	0.98 a	31.25 a	0.38 a	38.90 a	37.93 a
	BioIlsa 12,5	40		10.06 a	1.06 a	30.90 a	0.37 a	39.04 a	37.97 a
	Horn meal	40		10.99 a	0.94 a	31.60 a	0.36 a	38.27 b	37.22 a
			p≤	*0.081*	*0.120*	*0.222*	*0.467*	*0.023*	*0.053*
	Across fertilisers	40	broadcast	10.49 a	0.95 a	31.37 a	0.35 b	37.93 b	36.97 b
		40	strip	10.62 a	1.04 a	31.82 a	0.39 a	39.63 a	38.62 a
			p≤	*0.702*	*0.680*	*0.586*	*0.029*	*0.000*	*0.000*

* = Marketable grading size >35mm for Salome and Velox and > 30mm for Nicola

Different letters within columns indicate significant difference between treatments (Bonferroni-Holm multiple range test, P < 0.05).

Table 3. 7: Gross yield and ratio haulm/tuber dry matter (DM) at 75 dap, 95 dap and gross and marketable yield at main harvest of potatoes (cultivar Salome and Velox (2004) and Nicola (2005and 2006) spayed with biostimulants AUSMA (2004) and Biofeed Quality (2005and 2006) compared to water control, respectively.

Year / Cultivar	Product	Application	75 dap		95 dap		Main harvest	
			Gross yield $t*ha^{-1}$	Ratio Haulm/tuber DM	Gross yield $t*ha^{-1}$	Ratio Haulm/tuber DM	Gross yield $t*ha^{-1}$	Marketable yield $t*ha^{-1}$
2004 Salome	Ausma	$2*2.5l*ha^{-1}$	14.74 a	0.41 a	24.26 a	0.19 a	33.39 a	30.55 a
	Water control		15.85 a	0.37 a	24.96 a	0.18 a	32.15 a	29.21 a
		p≤	*0.594*	*0.463*	*0.149*	*0.352*	*0.465*	*0.454*
2004 Velox	Ausma	$2*2.5l*ha^{-1}$	17.05 a	0.31 a	24.86 a	0.20 a	33.69 a	32.67 a
	Water control		17.93 a	0.33 a	25.08 a	0.19 a	33.96 a	32.96 a
		p≤	*0.434*	*0.681*	*0.614*	*0.753*	*0.843*	*0.844*
2005 Nicola	BF- Qualtiy	$4*10l*ha^{-1}$	15.81 a	0.65 a	31.16 a	0.27 a	36.84 a	35.18 a
	Water control		14.17 a	0.66 a	30.80 a	0.24 b	34.89 b	33.42 b
		p≤	*0.076*	*0.988*	*0.749*	*0.048*	*0.034*	*0.020*
2006 Nicola	BF- Qualtiy	$4*10l*ha^{-1}$					33.73 a	33.13 a
	Water control						34.10 a	33.19 a
		p≤					*0.482*	*0.918*
* = Marketable grading size >35mm for Salome and Velox and > 30mm for Nicola								

Different letters within columns indicate significant difference between treatments (Bonferroni-Holm multiple range test,P < 0.05).

3.3.2.6. Tuber diseases

In 2004, black scurf infestation due to *R. solani* on both cultivars was lowest when fertilised with BFE. The amount of tubers of cultivar Salome but not Velox with less than 1 % black scurf infestation was significantly higher compared to all other treatments. There were no effects on tuber infestation with common scab (Table 3. 8).

In 2005, black scurf severity was significantly reduced by the spraying of BFQ. Across fertiliser and N-input levels, BFQ reduced mean black scurf infestation of the tuber surface by 1.84 % and increased the amount of tubers with a severity of less than 1 % by 15 % compared to the control (Table 3. 8). The values of black scurf and common scab for fertiliser products in 2005 were determined across fertilisation levels. Both fertilisers reduced black scurf severity somewhat compared to the non-fertilised plots. The effects were significant when comparing the amounts of tubers with less than 1 % severity (Table 3. 8). In 2006, mean black scurf severity was only insignificantly lower when fertilised with BI 12 and BFB, respectively compared to horn meal. However, the plant based fertiliser BFB reduced common scab significantly compared to the fertilisers BI 12 and horn meal which are based on animal residues. (Table 3. 8).

Table 3. 8: Black scurf (Ø tuber surface infestation (TSI) in %), % of tubers with black scurf ≤1 % and common scab (TSI in %; only ´04 and ´06) of potato cultivars Salome, Velox (´04) and Nicola (´05 a. ´06) fertilised with Biofeed Ecomix (´04), Biofeed Basis (´05 a. ´06) and BioIlsa 12,5 Export compared with the horn meal reference (´04 a.06) and a not N fertilised control treatment (Zero - ´04 a. ´05) and only in ´05 additionally sprayed with biostimulant Biofeed Quality.

Year / Cultivar	Product		Black scurf (% of tuber surface)	Black scurf <1% (% of tubers)	Common scab (% of tuber
2004 Salome	BF- Ecomix	Fertiliser	1.93 a	79.92 a	5.60 a
	BioIlsa 12,5 .	Fertiliser	4.19 a	61.67 b	6.28 a
	Horn meal	Fertiliser	4.08 a	57.50 b	5.60 a
	Zero		3.93 a	59.17 b	7.10 a
		p≤	*0.115*	*0.013*	*0.584*
2004 Velox	BF- Ecomix	Fertiliser	1.95 a	79.17 a	2.08 a
	BioIlsa 12,5	Fertiliser	2.88 a	77.50 a	1.46 a
	Horn meal	Fertiliser	2.93 a	64.17 b	1.84 a
	Zero		2.35 a	74.17 b	2.13 a
		p≤	*0.673*	*0.360*	*0.684*
2005 Nicola	BF- Basis	Fertiliser	3.37 a	65.00 a	*
	BioIlsa 12,5	Fertiliser	3.74 a	64.65 a	*
	Zero		4.46 a	55.83 b	*
		p≤	*0.065*	*0.011*	
	BF Quality	Biostimulant	2.94 a	69.21 a	*
	Water control	Spray	4.78 b	54.44 b	*
		p≤	*0.001*	*0.000*	
2006 Nicola	BF- Basis	Fertiliser	4.46 a	61.18 a	12.04 a
	BioIlsa 12,5	Fertiliser	4.62 a	56.77 a	16.47 b
	Horn meal	Fertiliser	5.92 a	56.09 a	15.76 b
		p≤	*0.492*	*0.889*	*0.011*
* not determined					

Different letters within columns indicate significant difference between treatments (Bonferroni-Holm multiple range test P < 0.05).

3.4. Discussion

Overall, the tested organic fertilisers Biofeed Ecomix (BFE - animal and plant derived), Biofeed Basis (BFB - plant derived) and BioIlsa 12,5 Export (BI 12 - animal derived) were able to supply considerable amounts of nitrogen to tomatoes and potatoes in the season after application and at the crucial time of nitrogen uptake of potatoes and tomatoes. This resulted in at least as high or higher yields than the control fertiliser horn meal in all trials with potatoes and tomatoes. The importance of fertiliser placement on N uptake efficiency was also clearly demonstrated as potato N-uptake was increased by 10 kg ha^{-1} by 95 days after planting (dap) if applied as strip compared with broadcast.

In comparison to the standard horn meal fertilised treatments especially BFB in combination with the biostimulants AUSMA and BioFeed Quality (BFQ) reduced late blight in tomatoes. BFQ also increased yields of tomatoes in all trials and that of potatoes in one year. There appeared to be some beneficial effects of BFQ on potato tuber diseases.

All tested fertilisers supplied considerable amounts of soil N-min during the main uptake phases of both crops resulting in adequate N uptake dynamics in potatoes compared to the horn meal reference. In potatoes, across fertilisation levels, 34-58 % of the N- input by fertilisers (compared to crop uptake without N-input) was taken up by haulms and tubers by mid July when applied directly into the potato row. Assuming that an additional 5-10 % of the nitrogen is used for roots and metabolic processes (Harris 1978, Marschner 1995) it can be deduced that about 40-65 % of the fertilisers had become plant available. According to Kolbe (2007) this is equal to the effectiveness to horn meal products and poultry manure in mineralization, but about 10 % higher than single compound plant based fertilisers. The N mineralization efficiency of BFB had been tested in an incubation experiment at constant 30 ^{0}C during 6 weeks in soil compared to bone meal, chicken pellets, blood meal and horn meal (Stutterheim, 2005). BFB had a relatively slow initial release of nitrogen, but after the first week a strong increase in N-availability took place. This trend continued until the end of the experiment. The N-release from BFB was nearly 50 % at week 6, while it was nearly 35 % for chicken-pellets and in between 25 and 30 % for the other biological materials resulting in a far better N-efficiency from BFB than from the other biological materials (Stutterheim, 2005). In contrast to these results, however, across the field trials reported here, BFB, BI 12, and the horn meal reference were rather similar in their effects on soil N dynamics and crop N – uptake.

The most effective with tomatoes were the combined treatments of fertiliser BFB and biostimulants AUSMA and BFQ. Both biostimulants significantly increased the share of healthy fruits when late blight severity was relatively high and/ or the number of fruits. The significantly higher late blight resistance in leaf inoculation tests and the reduction in number of infected fruits in the field trials by treatment with AUSMA and BF Quality suggest that the product induces some plant resistance mechanisms against the pathogen. This was confirmed by Sharma et al. (2007) who tested the effects of BFQ on the susceptibility of eight tomato varieties. Interestingly, resistance induction through BFQ was variety specific ranging from no to 47 % disease reduction relative to the water treated controls.

Overall, it appears that the seaweed containing fertiliser BFB combined with both BFQ (extract of several seaweed species with humic acids) and AUSMA (watery extract of pine and spruce needles) were able to improve tomato growth in general. A variety of mechanisms may be involved here including increased root development, nutrient uptake, chlorophyll content, and induced plant resistance. Whapham et al. (1993) demonstrated that seaweed extract, applied either to foliage or the soil, significantly increased the chlorophyll content in tomato leaves. They concluded that the effects of enhancing chlorophyll levels produced by the seaweed extract were due, at least in part, to betaines. Humic acids influence metabolism and morphology by interacting with a variety of biochemical mechanisms and physiological processes. They stimulate growth and increase the total amount of nutrients taken up by plants, influencing glycolysis and respiration pathways, and exert direct effects on the expression of genes encoding H+-ATPase isoforms and nitrate transports (Vaughan & Malcom, 1985; Canellas et al., 2002; Nardi et al., 2007).

Potato yield increases per kg applied nitrogen varied among cultivars and N-input levels but with the tested fertilisers between 9-20 kg more yield per kg N-input were achieved compared to horn meal. At moderate N–supply levels of 40 and 75 kg N ha^{-1} the efficiency of the tested fertilisers ranged between 90 and 159 kg yield kg^{-1} N–input. This is considerably more than was reported from a survey of several field trials with organically grown potatoes by Kolbe (2007). There different commercial organic fertilisers at 75 kg N ha^{-1} N-input resulted in yield increases of 13 to113 kg per kg N-input. One reason could be that in our trials the fertilisers were applied in strips. Assuming 130 kg yield increase per kg N–input, the same yields could be achieved with 26 kg N strip applied versus 40 kg broadcast application thus reducing input needs by about one third.

Potato yield was not affected by AUSMA treatment, whereas BF Quality significantly increased haulm growth and yield in 2005 (+ 6 %) and hence the N-input efficiency of fertilisers independent of fertiliser and N-input level. In 2006, however, no effects on yield were observed. Other studies on the effects of seaweed extracts on potato yield have produced variable results. Several studies reported that seaweed extract stimulated haulm development and photosynthesis (Blunden & Wildgoose 1977; Kolbe & Blau 1998; Neuhoff, 2002). However, Kolbe & Blau (1998) and Kürzinger (1995) found reduced numbers of tubers per plant and unaffected yields whereas Blunden & Wildgoose (1977) as well as Neuhoff (2002) reported increased tuber numbers and yields. It is likely that application management, extract formulation, production process and raw material origin and composition all may influence the effectiveness of seaweed extracts in potato production.

In contrast to tomatoes, potato late blight (*P. infestans*) infection was affected neither by fertiliser nor by biostimulant treatments in all years. However, in 2006, the plant derived BFB reduced infestation with common scab (*S. scabies*) compared with the animal derived fertilisers. Data on scab were only assessed in 2006, so that no conclusion can be made about a possible reduction potential and further tests are needed here. Effects on black scurf (*R. solani*) severity were also variable with significant reductions in 2005 by 38 % when sprayed with the biostimulant BFQ. Unfortunately, no assessments were made in the trial with BFQ in 2006. The effects of BFB and BI 12 fertilisers on black scurf were beneficial in 2005 but not in 2006. It is possible that BFQ might stimulate antagonist activity. Barretto et al. (1997 & 2002) found that ethanol extracts made of using the alga *Stypopodium zonale* (Lamouroux) Papenfuss from the East coast of South Africa tested in the laboratory by the pour plate technique inhibited the growth of *R. solani* at high concentrations but at low concentrations the growth of the pathogen was promoted. Fertiliser treatments had no effects on black scurf.

In conclusion, both fertilisers BF Basis and BioIlsa 12,5 Export performed well and can be used as alternatives to other fertiliser products used in organic systems. Particularly the plant based GMO-free BF Basis is of interest as demand of plant based fertilisers increased after the BSE crisis and there are concerns of using residues derived from intensive animal husbandry in organic farming. The biostimulants BF Quality and AUSMA resulted in some positive effects on plant growth and plant health status and could be a good measure to improve crop production in organic farming. Especially the combination of well adapted liquid and solid products can have promising effects on crop performance. However, further research is needed to determine the effects of the biologically active compounds in the fertilisers and extracts on plant metabolism and their interaction with soil life, plant growth and health. Also, timing, concentration and interval of application for respective crops need to be optimized to reach crop promoting effects.

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4. Suppressive composts can successfully reduce *Rhizoctonia solani* in organic potato production

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Abstract

Black scurf of potatoes, caused by *Rhizoctonia solani* is rapidly increasing in importance since the use of organically produced seed potatoes has become compulsory in organic potato production. No effective measure to control the disease is available for organic production. The suppressive effects of composts made of mixtures of organic household and green yard waste to control *R. solani* in potatoes were tested in field trials under organic conditions at the University Kassel in the years 2006 and 2007. Compost directly applied at the seed tuber area at 5 t DM ha^{-1}, significantly reduced both the infestation of harvested potatoes with black scurf and the percentage of tubers with malformations and dry core as well as increasing marketable yield and tuber number independently from initial seed tuber infection and cultivar. When same amounts of compost were applied broadcast disease suppression was much less effective particularly in no reduction of tuber malformations. The rate of initial infection of the seed tubers also affected tuber number, health and quality significantly. However, the up to 50 % disease reduction was achieved through compost application independent of initial infection. Development of a strip application technique for composts to control the disease is needed.

Keywords: Compost, *Rhizoctonia solani*, seed tuber health, organic potato production

4.1. Introduction

Black scurf of potato (*Solanum tuberosum* L.) caused by *Rhizoctonia solani* Kühn AG-3 [teleomorph: *Thanathephorus cucumeris* (Frank) Donk] is a common and commercially important disease found in all potato production areas (Anderson, 1982; Powelson et al., 1993; Jager et al., 1996). The disease can affect all underground parts of the plant at different times during the growing season. The disease cycle starts from germinating sclerotia in the soil and/or on planted potato seed tubers. The hyphae attacks sprouts which often leads to uneven and delayed crop emergence, a reduced number of stems per plant and poor root development. Later in the season, the pathogen causes symptoms with brown and black sunken lesions on the stems and stolons. The stem cankers can restrict the movement of water and nutrients within the plant often resulting in malformed tubers, uneven size distribution and reduced number of tubers (Banville, 1989; Jager &. Velvis, 1989; Scholte, 1989; Hide & Horrocks, 1994). Other symptoms affecting the tuber quality are the infection of the lenticels causing the ´dry core` symptom with dark brown holes in the tuber. Upon maturity, formation of black sclerotia starts on the tuber surface (black scurf symptom) and the severity of sclerotia infestation usually increases with the time the mature tubers are left in the soil. All those symptoms can considerably reduce the marketable yield. (Banville, 1989; Jager &. Velvis, 1989; Scholte, 1989; Hide & Horrocks, 1994). As the pathogen is as well soil as seed tuber borne the primary means to reduce black scurf in potatoes are the use of healthy seed tubers and field hygiene. Rhizoctonia-infested seed tubers are of importance in disseminating the disease and adding to the pool of soil-borne inoculum (Jeger et al., 1996). While conventional seed tubers are usually treated with fungicides, in organic systems until now there exist no reliable measures for the control of seed borne inoculum. Especially the production of organic certified healthy seed tubers poses serious problems. Since the use of organic seed potatoes has become compulsory in organic potato production black scurf is increasing in importance. To reduce soil borne infection it is important to ensure good soil conditions with a high microbial activity with a high antagonistic potential. Soil organic matter greatly increases soil microbial activity and diversity which, in turn, are related to soil and seed borne disease suppression (Lumdsen et al., 1983; Fließbach & Mäder, 2000). Such organic matter could be supplied by high quality suppressive biogenic waste composts. Suppressiveness of composts is closely related to colonisation by disease suppressive micro-organisms during curing e.g. *Bacillus spp., Enterobacte spp., Flavobacterium balustinum 299, Pseudomonas* *spp*., and other bacterial genera and *Streptomyces spp*. as well as fungal species including *Penicillium spp, Gliocladium virens,* several *Trichoderma spp*. and others (Chung & Hoitink, 1990; Hoitink et al., 1996). Application of high quality composts leads to sustained increases in microbial activity and the establishment of microbial populations with antagonistic features (Hoitink & Boehm 1999). The mechanisms of disease suppression are divided loosely into two categories described as "general" and "specific" (Baker and Cook, 1974). General disease suppression can be attributed to the activity of many different types of micro-organisms against pathogens including *Phytophthora* and *Pythium* spp. (Hoitink et al., 1996). Specific suppression occurs in the presence of specific hyper parasitic micro-organisms. *R. solani* suppression is one example, as sclerotia are colonised by specific hyperparasites (mainly *Trichoderma* spp.) which reduce inoculums' potential. Suppressive effects of high quality composts have been recorded from many studies but mainly in nursery trials (Nelson et al., 1983; Kuter et al., 1983; Chen et al. 1988; Schüler et al., 1989; Hoitink & Grebus, 1994; Hoitink et al., 1996; Termorshuizen et al., 1996; Bruns & Schüler, 2002). Promising results also have been obtained with suppressive composts against several soil-borne pathogens under field conditions (Hoitink & Fahy, 1986; Tunlid et al., 1989, Bruns et al., 2002) and Tsror et al. (2001) demonstrated that it might be possible to reduce *R. solani* on potatoes with application of 60 m^{3} * ha^{-1}cattle manure compost. Good suppressive effects against soil borne diseases not only depend on the quality but also generally on the amount of compost material applied. For example, Bruns et al. (2002) showed that at least 5-10 % compost is needed in potting mixtures to achieve reliable disease suppression. However, in organic farming, application of source separated household waste composts is limited to 5t dry matter (DM) compost ha^{-1} $year^{-1}$. To make use of such comparatively low amounts of compost in the field the compost needs to be applied directly to the place where it is needed, in the case of potatoes near the seed tubers to create the highest possible suppressive effects.

In this study, we conducted three field trials to test the effects of targeted compost application within the row during planting of potatoes on plant and tuber infection with *R. solani*. The following questions were addressed in this study: (i.) Is it possible to achieve disease control with compost applications of only 5 t DM * ha^{-1} in field grown potatoes and can this be enhanced by application technology? For this, we compared broadcast and strip application of compost. (ii.) How effective are composts when used with tubers varying in initial black scurf infestation? (iii.) Do the suppressive effects vary among potato cultivars varying in maturity?

4.2. Materials and Methods

The trials were conducted at two experimental farms of University of Kassel in Witzenhausen in the years 2006 and 2007 to evaluate a compost application system with row application during planting of potatoes for its suppressive effects. Trials 1 and 2 were conducted at experimental station Hebenshausen, located about 8 km to the north-west of Witzenhausen, at an average height of 250 m above sea level. Fields have been converted to organic farming in 1998.The soil type of the experimental field is a homogeneous deep gleyed loess-leached brown soil. The German ”Reichsbodenschätzung” (land evaluation) qualified the index of the soil at 74 points (max. 100 points).The mean annual precipitation amounts to 612 mm and the average temperature is 7.9° C (Wildhagen, 1998).
Trial 3 was conducted at the experimental farm Hessische Staatsdomäne Frankenhausen in 2007, located 230 meters above sea level. The farm had been converted to organic farming between 1999 and 2001. The soil type of the experimental field was a Haplic Luvisol, soil texture a silt loam (Ut3, 12- 17 % clay, 65- 88 % silt, 0- 13 % sand) (Finnern et al., 1994, Brandt et al., 1998). Annual precipitation is 650 mm with an average annual temperature of 8.5 °C.

4.2.1. Compost

All composts were made according to EEC regulation No 2092/91 (Annex II). The regulation stipulates that composts must be produced in a closed and monitored collection system, accepted by the member state. Maximum allowed heavy metal concentrations in mg/kg of dry matter are: Cadmium: 0.7; copper: 70; nickel: 25; lead: 45; zinc: 200; mercury: 0.4; chromium (total): 70

Two composts were used: *Compost A*: 5 month old compost composted at a public composting site according to German regulations (BGK 1998): Raw material consisted of 60 % source separated organic household wastes and 40 % yard waste. Compost A was used in all field trials in both years. In 2007, in addition 15 month old 100 % yard waste compost, composted at the University site (*Compost B*) was tested. Compost properties are summarised in Table 4.1.

Table 4 1: Properties of composts used in the field trials

Sample	Compost 2006	Compost A 2007	Compost B 2007
Dry matter (%)	69,0	79,1	70,2
NO_3-N mg kg dm^{-1}	392	433	388
NH_4-N mg kg dm^{-1}	98	107	89
Electrical conductivity (µs)	3120	2920	656
pH	7,65	7,65	7,3
P mg kg dm^{-1}	2060	1700	1611
K mg kg dm^{-1}	14400	12000	1357
N_t (%)	1,81	1,71	1,48
C_t (%)	20,97	17,69	20,43
C-N Ratio	11.57 :1	10.34 :1	13.82 :1

Composts were applied at 5t DM ha^{-1} in all trials. For the row application composts were applied directly to the seed tuber area by using a modified fertiliser application machine (Universal Kastenstreuer, UKS 150, Rauch, Sinzheim).

4.2.2. Trial 1: Effects of broadcast versus strip application:

In 2006, a one-factorial field trial comparing broadcast before planting and `strip´ into the planting furrow, thus in the direct surrounding of the seed tuber was conducted as strip-plot design with four replications. Certified seed tubers of the cultivar Nicola were used with an initial infestation of tuber surface with black scurf sclerotia below 1 %. Planting date was May 3rd, 2006. Each plot had six rows with 6.7 m length each.

4.2.3. Trial 2. Interactive effects of suppressive composts and different initial seed tuber infection levels

In 2006 and 2007, a three-factorial field trial was performed as split-plot design with four replications.

Factor a: Compost application vs. control. In both years, control plots without compost received an N, P, K –nutrient-equivalent (2.45 and 2.7 kg N, 10.3 and 8.5 kg P, 72 and 60 kg P *ha^{-1} in 2006 and 2007, respectively) to the household/yard waste compost nutrient load by application of horn meal, 14 % N (Oscorna, Ulm, Germany), ”Patentkali”, 30:10 K_2SO_4: MgO (Kali und Salz AG, Kassel, Germany) and rock phosphate ”Hyperphos 27”, 27 % P_2O_5 (Fa. Temag, Germany). In 2007, yard waste compost (see Table 4.1) was added as a second compost treatment.

Factor b: Initial infection: Naturally with black scurf infected seed tubers (cultivar Nicola - second generation) sorted into three infection classes (low ≤ 1 %, middle 2-5 % and high > 10 % infestation of tuber surface area) were used as planting material.

Factor c: Harvesting date: To determine the effect of the time the mature tubers remained in the soil on black scurf infestation tubers were harvested in two batches, two weeks and four weeks after plant death, respectively.

Planting dates were May 4th, 2006 and April 18th, 2007, respectively. Each plot had six rows with 6,7m length each. Plants of row one and six were used to assess stem canker. Row two and three were used for harvest 1 and row four and five for harvest 2, respectively. In 2007, due to very early infection with late blight (beginning of June) copper fungicides were applied (6 * 500g CuOH * ha^{-1}) to prolong the vegetation period.

4.2.4. Trial 3. Effects of suppressive composts on different potato varieties

In 2007, a two-factorial field trial was performed as split-plot design with three replications.

Factor a: *Compost A* vs. control. Control plots without compost received an N, P, and K – nutrient-equivalent to the household/yard waste compost nutrient load.

Factor b: Cultivar performance: Twelve cultivars of the maturity groups early; medium early, medium late and medium late to late were planted.

Planting date of the pre-germinated seed tubers was April 18th, 2007, harvesting date October 2nd, 2007. No copper fungicides were applied in this trial.

4.2.5. Disease assessment

All assessments of symptoms of *Rhizoctonia solani* were performed according to the EPPO – standard PP 1/32 (2) (EPPO, 2000). The assessments of stem canker severity were conducted at the beginning of tuber formation (BBCH-Code 41-43) and classified with a gradation of 0.33 into the following classes: 1= no infestation, 2= < 1/3 of the subterranean part of the stem infested, 3= 1/3 to 2/3 of the subterranean part of the stem infested, 4= > 2/3 of the subterranean part of the stem infested, 5= stem dead. Assessments were done on all stems of 10 plants per plot. Tuber symptoms were assessed on 100 marketable tubers per plot of each cultivar.

Black scurf severity was assessed as mean percentage infestation of tuber surface. Percent incidence of tubers with dry core and malformations were also recorded. Marketable yield consisted of tubers of marketable size without malformations or dry core and with black scurf infestation of less than 15 %.

4.2.6. Data analysis

Statistical analysis was based on the SPSS GLM procedure (version 13). All data of *R. solani* symptoms were calculated in percentage values and arc sine transformed before analysing. The *Kolmogorov-Smirnov test* was conducted to analyse the normal distribution.

Data were analysed by fixed effect models per compost treatment, initial seed tuber infection and harvest date. Due to the split plot design the interaction between replication and compost treatment was used as random effect. The *Bonferroni-Holm* Test was conducted to separate means with a confidence level of 95 %.

4.3. Results

Weather conditions differed greatly between the two years. The spring 2006 was relatively cold (March and April 1.6°C lower than the long-time average) followed by a long hot and dry period starting June 8th until beginning of August (June +1.3 °C – 30 $l*m^2$, July +4.4°C -49 $l*m^2$ compared with the long-time average) (Table 4. 1). The spring 2007, in contrast, was relatively hot until mid May (March- May +2.2 C) and had a dry April with nearly no precipitation followed by a long wet period until harvest (May- August + 176 $l*m^2$ (Table 4. 1). Consequently, in 2006, late blight did not play an important role, starting on August 8th only and thereafter increased slowly until plant senesced. In 2007, however, late blight started unusually early on June 5th at a time when the potatoes had not yet been able to accumulate much yield. In trial 2 where copper was used the crop died in the beginning to mid August while in trial 3 crop death due to late blight occurred already in early July.

Table 4. 1: Climatic conditions at the experimental station Eichenberg during the growing periods of 2006 and 2007 as well as the average for 1991-2001. (Source: Mean 1991-2001 calculated by the Department of Forage Production and Grassland Ecology; Data from 2006 and 2007 measured by the Department of Ecological Plant Protection)

Month	Mean air temperature °C			Precipitation in mm		
	1991 - 2001	2006	2007	1991 - 2001	2006	2007
January	1.0	-2.2	5.0	49	12	104
February	1.3	-0.2	4.4	43	32	53
March	4.7	1.7	6.3	56	53	65
April	8.1	7.9	11.4	45	44	2
May	12.6	13.3	14.0	50	79	144
June	15.0	16.3	17.3	69	39	142
July	17.4	21.8	16.9	75	26	87
August	17.5	15.7	15.6	62	73	77
September	13.1	17.1	12.8	61	10	116

4.3.1. Effects of broadcast and strip application of compost on Rhizoctonia solani symptoms

Dry core symptoms could not be observed in that trial (2006). Both placements of compost, as strip incorporated into the ridge and the broadcast application led to a significant reduction of black scurf ($p \leq 0.009$ and $p \leq 0.018$) and number of tubers with an infestation of more than 1 % ($p \leq 0.022$ and $p \leq 0.049$) compared to the control (Figure 4. 1). However, only ridge application led to significant reductions of tuber malformations ($p \leq 0.027$) and consequently, the effects on marketable yield were also larger (Figure 4. 1).

Within all symptoms ridge application showed a higher suppression than the broadcast application. Black scurf tuber surface infestation was by 0.69 % and tubers with an infestation of more than 1 % by 8.47 % lower when compost was applied in the ridge compared to a broadcast application. However, most important was the distinctly reduction of malformed tubers by 4.73 % (Figure 4. 1) resulting in a significantly marketable yield increase of 3.3 t ha^{-1} (not shown).

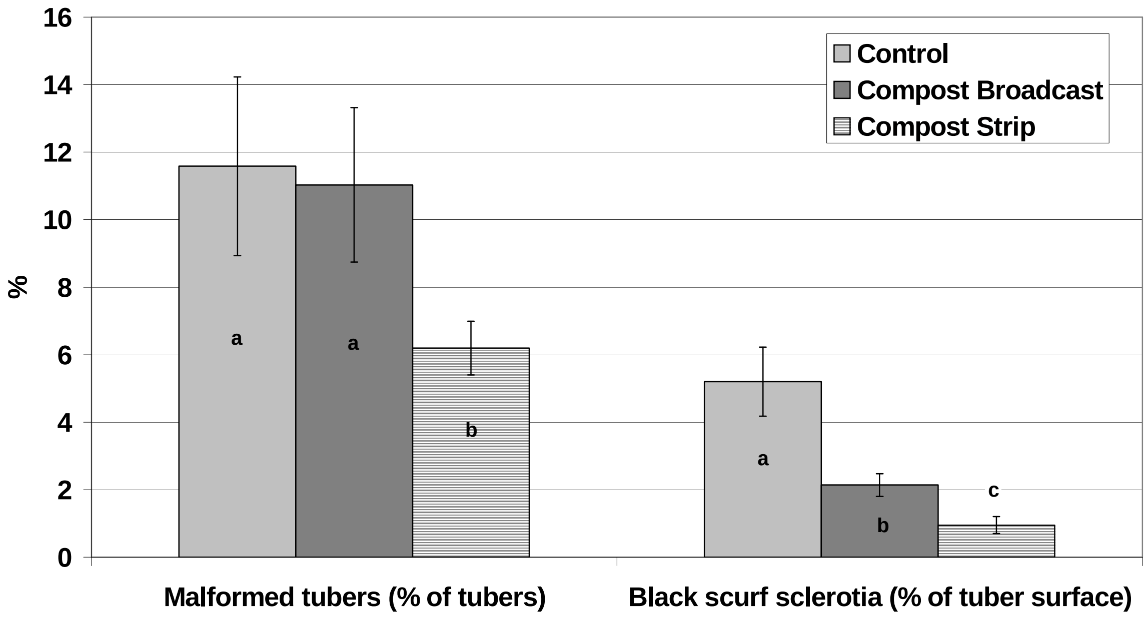

Figure 4. 1.: Malformed tubers (%) and black scurf infestation of harvested tubers in percent of the tuber surface of treatments broadcast and strip application placements of compost (5t DM ha^{-1}) compared to a nutrient equivalent control without compost.

Means were separated by Bonferroni-Holm multiple range tests ($P < 0.05$). Different letters indicate significant differences among treatments. Prior to analysing percentage data were arcsine transformed.

4.3.2. Effects of compost application in the potato ridge and initial seed tuber infection with black scurf on incidence of Rhizoctonia solani symptoms

Overall, stem canker symptoms were lower in 2006 (severity index = 1.86) than in 2007 (index = 2.11). In both years, strip application of suppressive composts and initial seed tuber infecting significantly reduced stem canker severity. Compost A in both years and compost B in 2007 reduced stem canker by 0.53 to 0.72 index points compared to the control. Compared to the level of stem canker on plants stemming from tubers with low initial infection stem canker increased by 0.4 and 0.72 (2006) and 0.49 and 0.75 (2007) for plants stemming from tubers with mid and high initial infection levels, respectively (Table 4. 2).

Table 4. 2: Stem canker index (EPPO – standard PP 1/32 (2)) in 2006/07 after application of two suppressive composts in dependence of three seed tubers infestation severities with black scurf.

Treatment	Stem canker index 2006				Stem canker index 2007			
	Initial seed tuber infection			Mean[1]	Initial seed tuber infection			Mean[1]
	< 1%	2-5%	> 10%		< 1%	2-5%	> 10%	
Compost A	1.23	1.63	1.95	1.60 a	1.53	2.08	2.23	1.95 a
Compost B					1.50	1.90	2.11	1.84 a
Control	1.75	2.15	2.48	2.13 b	2.07	2.60	3.01	2.56 b
Mean[1]	1.49 a	1.89 ab	2.21 b		1.70 a	2.19 b	2.45 c	

[1] mean of treatments and initial seed tuber infection followed by different letters are significantly different (Bonferroni-Holm multiple range test, $P < 0.05$).

Tuber symptoms differed between the years. In contrast to 2007, no differences between the harvesting dates could be observed in 2006. Thus, for 2006 mean values of both harvests are shown (Table 4. 3). ”Dry core” symptoms (infected lenticels) could only be observed in 2007 while malformations of tubers were about 10 % higher in 2006 than in 2007 (Table 4. 3 and Table 4. 4). In both years, black scurf (2006 $p \leq 0.002$; F 14.9; 2007 $p \leq 0.003$; F =19.0) and malformed tubers (2006 $p \leq 0.001$; F 19.5; 2007 $p \leq 0.002$; F = 22.3) and, in 2007, ”dry core” ($p \leq 0.003$; F = 18.8) were significantly reduced by ridge application of compost. Composts reduced black scurf incidence by 20 to 38 %, malformed tubers by 27 to 45 % and dry core by 38 %. Differences between the composts in 2007 were small with slightly higher disease suppression by compost A (Table 4. 3 and Table 4. 4).

All tuber symptoms were affected considerably by the initial seed tuber infection in both years. Initial seed tuber infection affected black scurf incidence much more in 2007, increasing by 88 and 154 % with middle and high initial seed infection, respectively ($p \leq 0.000$; F =161.0 than in 2006 (increases of 26 and 46 %, respectively, $p \leq 0.001$; F =11.2). The amount of tuber malformations were also significantly affected by seed tuber health in both years (2006: $p \leq 0.004$; F = 8.1; 2007: $p \leq 0.000$; F = 88.5). An initial seed tuber infection of 2-5 % and 10 % led to a higher amount of malformed tubers in 2006 by 6.0 % and 11.8 % and in 2007 by 2.5 % and 6.2 % compared to an initial infection with 1 % or less, respectively (Table 4. 3 and Table 4. 4).

Table 4. 3: Black scurf infestation (% of tuber surface) and percentage of malformed tubers in 2006 after application of suppressive composts in dependence of three seed tubers infestation severities with black scurf.

2006	Black scurf (% of tuber surface)				Malformed tubers(%)			
Treatment	Initial seed tuber infection			Mean[1]	Initial seed tuber infection			Mean[1]
	< 1%	2-5%	> 10%		< 1%	2-5%	> 10%	
Compost A	2.04	2.85	3.03	2.64 a	7.75	14.75	14.75	12.42 a
Control	2.82	3.3	3.78	3.30 b	15.75	20.75	32.25	22.92 b
Mean[1]	2.43 a	3.07 b	3.40 c		11.75 a	17.75 b	23.5 c	

[1] mean of treatments and initial seed tuber infection followed by different letters are significantly different (Bonferroni-Holm multiple range test, P < 0.05).

In 2007, leaving the tubers two additional weeks in the soil increased black scurf incidence by 36 % ($p \leq 0.000$; F = 41.5). Due to the later harvest the amount of tubers with”dry core” increased across all seed tuber infection classes on average by 87 %, which resulted in a highly significant interaction between seed tuber health and date of harvest ($p \leq 0.001$; F = 8.2) (Table 4. 4) The amount of malformed tubers was not significantly affected by the date of harvest (Table 4. 4).

Table 4. 4: Black scurf infestation (% of tuber surface), percentage of tubers with malformations and infected lenticels (”dry core”) in 2007 after application of two suppressive composts in dependence of three initial seed tubers infestation severities with black scurf.

2007	Harvest - days after crop death	Black scurf (% of tuber surface)				Malformed tubers (%)				Infected lentcels "dry core" (%)			
		Initial seed tuber infection			Mean[1]	Initial seed tuber infection			Mean[1]	Initial seed tuber infection			Mean[1]
		< 1%	2-5%	> 10%		< 1%	2-5%	> 10%		< 1%	2-5%	> 10%	
Compost A	14	1.4	2.6	3.3	2.7 a	3.4	4.9	9.5	6.1 a	2.3	4.5	4.3	5.0 a
	30	1.1	3.2	4.8		3.2	5.5	10.4		3.2	6.5	9.3	
Compost B	14	1.0	2.8	3.8	3.0 a	3.4	6.0	8.9	6.7 a	1.4	3.9	5.0	5.1 a
	30	1.8	3.6	4.9		4.4	7.7	10.0		3.2	6.2	10.9	
Control	14	2.7	3.8	5.1	4.4 b	5.9	8.7	12.4	9.3 b	3.9	4.9	8.1	8.2 b
	30	3.2	5.0	6.5		6.6	9.1	13.3		6.9	9.6	15.8	
Mean harvest date[1]	14	1.7	3.1	4.0	2.5 a	4.3	6.5	10.3	7.0 n.s.	2.6 a	4.5 ab	5.8 bc	4.3
	30	2.0	3.9	5.4	3.3 b	4.7	7.4	11.2	7.8 n.s.	4.4 ab	7.4 c	12.0 d	8.0
Mean[1]		1.9 a	3.5 b	4.7 c		4.5 a	7.0 b	10.7 c		3.5	5.9	8.9	

[1] Means of treatments, harvest date and initial seed tuber infection followed by different letters are significantly different (Bonferroni-Holm multiple range test, P < 0.05).

Overall, the number of tubers per plant was strongly affected by the year. In 2006, each plant produced 4.7 tubers more than in 2007. Compost application and initial seed tuber infection affected the tuber number significantly in both years (Table 4. 5). Like with final disease levels, initial seed tuber infection also had the strongest effects on the number of tubers (2006: $p \leq 0.000$; $F = 20.3$; 2007 $p \leq 0.000$ $F = 31.2$) (Table 4. 5). Mean marketable yield in 2007 was about 5.37 $t*ha^{-1}$ lower than in 2006. Application of the household/yard waste compost (A) increased marketable yields between 22 and 25 % in both years while the older yard waste compost (B) in 2007 resulted in increases of 15 % (Table 4. 5).

Initial seed tuber infection had huge effects on marketable yield and the number of tubers per plant in both years. Yields of treatments with initial seed tuber infection of 2-5 % were reduced by 12 % and 18 % and tuber number by 2 % and 12 % compared to treatments with initially healthy seed tubers in 2006 and 2007, respectively. When initial infection was more than 10 %, yields were reduced by 26 % and 34 % and tuber number by 9 % and 22 % in the respective years (Table 4. 5).

Table 4. 5: Marketable yield of potatoes (<15 % black scurf, no malformation and dry core) and number of tubers per plant in 2006/07 after application of two suppressive composts in dependence of three seed tuber infestation severities with black scurf, respectively.

	Initial seed tuber infect.	2006			2007			
		Comp. A	Control	Mean[1]	Comp.A	Comp.B	Control	Mean[1]
Marketable yield $t\ ha^{-1}$	< 1 %	25.3	21.6	23.4 a	19.8	18.4	16.4	18.2 a
	2 - 5 %	22.7	18.6	20.7 b	16.0	15.1	13.5	14.9 b
	> 10 %	20.3	14.3	17.3 c	13.3	12.6	10.2	12.0 c
	Mean[1]	22.8 a	18.2 b		16.4 a	15.4 a	13.4 b	
Tubers $plant^{-1}$	< 1 %	14.2	13.0	13.6 a	10.2	9.1	9.2	9.5 a
	2 - 5 %	13.7	13.2	13.4 a	8.8	8.4	7.9	8.4 b
	> 10 %	12.9	12.0	12.5 b	7.7	7.6	7.0	7.4 c
	Mean[1]	13.6 a	12.7 b		8.9 a	8.4 ab	8.0 b	

[1] mean of marketable yield and tubers per plant within years followed by different letters are significantly different, respectively (Bonferroni-Holm multiple range test, $P < 0.05$).

4.3.4. Effects of ridge application of compost on Rhizoctonia solani symptoms on 12 cultivars of different maturity

The cultivars differed significantly in tuber malformations ($p \leq 0.006$; $F = 3.1$) and dry core ($p \leq 0.000$; $F = 5.1$) while differences in black scurf were not statistically significant due to high standard deviations (Table 4. 6). Across all cultivars, compost significantly reduced all assessed symptoms of *R. solani* (black scurf $p \leq 0.000$; $F = 85.3$, malformations $p \leq 0.000$; $F = 34.8$; dry core: $p \leq 0.000$, $F = 82.5$). However, reduction potential of compost differed among cultivars and tuber symptoms. Thus, dry core symptoms where reduced by compost on all cultivars by at least 2.75 %. In contrast, black scurf severity reductions ranged from 75.4 % for cv. Marabel 9.6 % for cv. Tizia with a mean of 49.5 % for all the cultivars. Tuber malformations were strongly reduced for all cultivars except Gunda and Tizia. (Table 4. 6)

Average marketable yields were relatively low at 16.4 t ha^{-1}, because of the early crop death due to late blight (beginning of July). The factor cultivar had the strongest effect on the marketable yield ($p \leq 0.000$; $F = 48.4$) (Table 4. 7). Compost application increased marketable yields significantly on average across all cultivars ($p \leq 0.000$; $F = 34.8$) compared to the control. Yield increases ranged from 0.1 to 4.8 t ha^{-1} with the exception of the lowest yielding cultivar Fasan for which yield decreased by 1.5 t ha^{-1} compared to the control (Table 4. 7). The interaction of cultivar and compost treatment was just not statistically significant ($p \leq 0.051$; $F = 2.1$).

The analysis of tuber number per plant showed a significant block effect ($p \leq .014$; $F = 4.8$). However, across all cultivars, compost increased the number of tubers by 0.8 per plant compared to the control, but with large differences among the cultivars. Ditta and Fasan had the same and Laura (-1. 5) a reduced number of tubers per plant, whereas the number of tubers was increased for the cultivars Agila, Agria, Edelstein and Nicola by more than one tuber per $plant^{-1}$ (Table 4. 7).

Table 4. 6: Black scurf incidence (% of tuber surface), malformed tubers (% of tubers) and tubers with ”dry core” (% of tubers) all caused by *R.solani* of 12 cultivars of different maturity after application of suppressive compost compared to a nutrient equivalent control.

Cultivar	Maturity	Black scurf (% of tuber			Malformations (% tubers)			Dry core (% tubers)		
		Compost	Control	Mean[1]	Compost	Control	Mean[1]	Compost	Control	Mean[1]
Agila	early	2.1	4.7	3.4 a	6.8	8.6	7.7 ab	5.7	10.1	7.9 abcd
Belana	early	2.8	8.0	5.4 a	6.6	14.0	10.3 ab	9.0	13.8	11.4 d
Gunda	early	2.7	4.4	3.5 a	6.1	6.3	6.2 ab	2.3	10.1	6.2 abc
Marabel	early	1.8	7.4	4.6 a	4.6	8.8	6.7 ab	5.4	11.7	8.6 abcd
Agria	medi. early	3.3	5.6	4.4 a	8.7	12.2	10.4 b	6.0	16.3	11.1 cd
Ditta	medi. early	3.3	5.0	4.2 a	6.1	8.5	7.3 ab	6.2	9.5	7.9 abcd
Edelstein	medi. early	2.5	5.4	4.0 a	8.0	13.7	10.9 b	5.5	15.3	10.4 bcd
Laura	medi. early	3.3	5.1	4.2 a	2.7	7.9	5.3 a	5.8	13.5	9.7 abcd
Nicola	medi. early	1.7	3.9	2.8 a	4.3	9.1	6.7 ab	3.3	6.7	5.0 ab
Fasan	medi. late	2.3	4.4	3.4 a	7.2	9.1	8.1 ab	3.3	6.0	4.7 a
Jelly	medi. late-late	2.0	5.0	3.5 a	3.9	10.7	7.3 ab	5.5	11.0	8.3 abcd
Tizia	medi. late-late	4.1	4.6	4.4 a	4.6	5.0	4.8 a	5.0	13.1	9.1 abcd
	Mean[1]	2.7 a	5.3 b		5.8 a	9.5 b		5.3 a	11.4 b	

[1] Parameter means of treatments and cultivars followed by different letters are significantly different (Bonferroni-Holm multiple range test, $P < 0.05$).

Table 4. 7: Marketable yield of potatoes (t/ha) (<15 % black scurf, no malformation and dry core) and tubers per plant of 12 cultivars of different maturity after application of suppressive compost compared to a nutrient equivalent control.

		Marketable yield t ha^{-1}			Tubers $plant^{-1}$		
Cultivar	Maturity	Compost	Control	Mean	Compost	Control	Mean
Agila	early	18.8	15.2	17.4 de	14.6	11.5	13.4 de
Belana	early	13.1	8.5	11.2 fg	14.2	13.6	14.0 cd
Gunda	early	18.3	18.2	18.3 cd	17.7	17.2	17.5 a
Marabel	early	25.2	20.8	23.5 a	16.3	15.8	16.1 ab
Agria	medi. early	22.7	19.0	21.2 abc	10.7	9.7	10.3 g
Ditta	medi. early	14.8	13.6	14.3 ef	11.5	11.5	11.5 g
Edelstein	medi. early	11.5	9.6	10.8 fg	14.2	12.6	13.6 cde
Laura	medi. early	21.5	15.7	19.2 bcd	14.0	15.5	14.6 bcd
Nicola	medi. early	23.6	20.0	22.2 ab	16.1	13.6	15.1 bc
Fasan	medi. late	7.8	9.2	8.4 g	11.8	11.8	11.8 fg
Jelly	medi. late-late	26.4	21.7	24.5 a	14.2	13.3	13.8 cd
Tizia	medi. late-late	11.9	11.2	11.6 fg	12.2	11.7	12.0 efg
	Mean	18.0 a	15.2 b		14.0 n.s.	13.2 n.s.	

Statistical Analysis (ANOVA) applying the fixed effect model (type III (a), means were separated by Bonferroni-Holm multiple range test ($P < 0.05$). Different letters within columns indicate significant difference between treatments. Percentage data were arcsine transformed

4.4. Discussion

Overall, row application to potatoes at planting of 5t DM ha^{-1} high quality composts composed either of a mix of biogenic household and yard wastes or of yard wastes only significantly reduced tuber and plant symptoms of *R. solani.* Increases in marketable yields were highly significant over two climatically very different years. Cultivar specific effects were tested in the second year only when disease pressure was much higher, however. There, marketable yields were increased on 10 out of 12 cultivars. The positive effects of composts were additive with the positive effects of using healthy seed tubers. Across the differences in initial seed tuber infestation (Trial 2) and cultivars (Trail 3) 5t DM ha^{-1} of high quality composts incorporated in the ridge reduced the infestation of harvested potatoes with black scurf, tuber malformations and dry core tubers by 20 to 84 %, 20 to 49 % and 38 to 54 %, respectively, resulting in marketable yield increases of 5 to 25 %. The higher amounts of tubers per plant produced in the presence of compost suggest a reduced loss of stolons through stem cankers caused by *Rhizoctonia***.**

The results confirm several studies that documented the suppressive effect of high quality compost amendments against soil borne diseases like *Rhizoctonia, Pythium* and *Fusarium* in potting mixtures and under field conditions (Nelson et al., 1983, Kuter et al., 1983, Hoitink and Fahy, 1986; Chen et al., 1988; Tunlid et al., 1989; Termorshuizen et al., 1996; Hoitink et al., 1997; Bruns and Schüler, 2000; Tsror et al., 2001). However, compost application amount in organic agriculture is limited at 5t DM ha^{-1} $year^{-1}$ and the studies reporting successes in suppressive effects relatively high amounts of compost were used. Thus, Tsror et al. (2001) applied $60m^3$ ha^{-1} (amounting to 15-25 t DM), while in the greenhouse studies 10-50 % compost were added to the potting mixtures (Chung & Hoitink, 1990; Hoitink et al., 1996, Bruns & Schüler, 2000). By that reason effectiveness of compost application placements targeted close to the seed tubers was compared with broadcast application. The targeted application (ridge) of compost was considerably superior in reduction of *R. solani* symptoms especially in the amount of tuber malformations. Therefore, there is a need to develop a targeted application system to achieve reliable control of *R. solani* with the limited compost amount of 5t DM ha^{-1}.

As expected, severity of *R. solani* was significantly affected by seed tuber black scurf severity and increased from low (<1 %) to middle (2-5 %), to high (>10 %), respectively. Initial infection also affected the number of tubers per plant and consequently on marketable yield confirming the results of Karalus (2003) who reported similar effects of seed tuber health on yield and disease under organic management. The use of compost reduced *R. solani* severity within all infection classes about as much as using the respective lower infection class. Thus, our results show that limiting the initial seed tuber infection level combined with compost application should significantly improve the situation for organic potato production. This should also reduce the addition inoculum to the soil (Jager et al., 1996),

Compost considerably reduced tuber dry core on all 12 cultivars tested, but failed to reduce black scurf on the late maturing Tizia and tuber malformations on Tizia and the early maturing Gunda. Our results suggest that there might be cultivar specific differences which might, in addition, interact with the effects of compost on disease. While there were no differences in black scurf severity, significant differences were observed for tuber malformations and dry core with the early cultivar Belana and the medium early cultivars Agria and Edelstein, the most susceptible cultivars to tuber defects caused by *R.solani*. Although both composts used were successful in reducing the disease, they were not equal. For consistent disease control, compost quality must be high. Beneficial effect provided by composts is substrate decomposition level dependent. Fresh organic matter releases high concentrations of free nutrients (glucose) which represses enzymes produced by *Trichoderma spp*. required for parasitism and eradication of sclerotia of plant pathogens such as *R. solani* (Nelson et al, 1983Hoitink and Boehm, 1999). In contrast Kuter et al, 1983 found that *Trichoderma spp,* which colonize the compost after peak heating (Kwok et al, 1987) are the most abundant taxa in mature composts prepared from lignocellulosic wastes. Therefore, to produce composts with suppressive effects to *R. solani* the use of ligneous raw and a controlled composting process is of major importance.

Moreover inoculation of specific biocontrol agents like *Trichoderma* spp. into the compost after peak heating could enhance those suppressive effects (Nelson et al., 1983, Hoitink and Fahy, 1986) and might be an additional measure to improve the system and should be tested.

Overall, the results indicate that strip application of 5t DM ha^{-1} of high quality compost at planting directly around the tubers could be a promising tool in the management of *R. solani* in organic farming. If combined with the use of healthy seed tubers it could especially contribute to high quality organic seed tuber production.

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5. Summarizing discussion

Organic farming depends on a long-term integrated approach and it is important to recognise the complex relationships that exist between different system components and that the sustainability of the system is dependent upon the functioning of a whole integrated and inter-related system (Atkinson & Watson 2000). In this system, the interactive effects of plant nutrition and disease play a central role as soils are only fertile if the plants growing in them are healthy and thus productive. Supplying adequate amounts of nutrients to plants at the right time poses the main challenge to organic plant production. The second main challenge is to produce healthy plants that can make use of these nutrients. However, plant nutrition and plant health cannot be dealt with separately. This is shown in this thesis in an exemplary way as well for the foliar disease late blight of potatoes and tomatoes, caused by *Phytophthora infestans* as for the soil and tuber borne black scurf of potatoes, caused by *Rhizoctonia solani*.

The article in Chapter 2 deals with the estimation of yield loss due to potato foliar late blight epidemics as influences by nitrogen supply. Yields in organic production are generally between 30-40 % lower than in conventional production (Möller & Meinck, 2003, Tamm et al 1999). While *P. infestans* is often claimed to be the main yield limiting factor in organic potato production Möller et al. (2006) pointed out that this view is oversimplified. His empirical results were confirmed by our modelling approach.
Within Europe, the economic impact of late blight varies between countries and regions. This is due to a variety of factors, but in organic production systems differences in climatic conditions, potato varieties used and agronomic techniques are thought to be important factors (Tamm et al. 2004). The most effective method of preventing damage in conventional production is to protect the plants with systemic fungicides. Protective copper fungicides are currently used to control late blight in most organic production systems, but approval for their use in organic farming will be revoked in 2008. Until 31 December 2008, 6 kg ha^{-1} and year are permitted (EU regulation). Furthermore, in Germany some organic farming associations limit the maximum copper application to 3kg ha^{-1} and year. Nevertheless, there are great concerns about the use of copper fungicides. As it accumulates in soil copper can harm soil microbial life and earthworm populations after long term application which is not in line with the aims of organic agriculture. It has been estimated that copper fungicides may extend the healthy leaf area duration by between 10-

30 days resulting in 10 to 40 % higher yields compared to crops not protected with copper (Tamm et al. 2004, Böhm, et al.2003). However, those estimations are based on calculations from conventional systems where nutrient supply usually is not limited. From our experimental work it became clear that copper fungicides in most cases do slow down epidemics somewhat. Over three years, 2002-2004, applying copper extended the growth duration by an average of 3 days only, however, and only 30 % of the variation in yield could be attributed to disease reductions. Our model including disease reduction, growth duration and temperature sum from planting until 60 % disease severity was reached, and soil mineral N contents at 10 days after emergence could explain 75 % of the observed variation in yield. However, the model failed when N-supply was with 280 kg N ha^{-1} extremely high. That high N-level prolonged haulm growth extremely and delayed nutrient transfer into the tubers. In turn, the premature death caused by late blight then greatly reduced yield. This is in accordance to the statements in the literature, that higher N-supply delays tuber formation and maturity and enhances the risk of yield losses under organic condition (Harris, 1978; Marschner, 1995; van der Zaag, 1992, Möller et al. 2003, Möller et al. 2007). Such extremely high N- supplies in organic (and conventional) potato production need to be avoided in general, however, because of the increasing risk of N leaching after harvest. Harvesting activates the mineralization processes and it is usually not possible to establish a proper catch crop in the relatively short period between harvest and winter.

A comprehensive analysis of our data together with data from trials in 2005 and 2006 revealed that the nitrogen uptake by mid July has the strongest impact on the final yield and (Hayer, 2008). Sequential harvests showed that with an N- supply of 70-90 kg ha^{-1}, final yields were already reached in the beginning to mid July. At that time, usually, the late blight epidemics just started and thus had no effect on the yield. Our results are similar to those of Möller et al. (2006). They analysed data from a farm survey in southern Germany and showed that the N-status of the crop explained 73 % of the yield variations whereas only 25% of this variation in yield could be attributed to the influence of late blight. Furthermore, they showed that, depending on the total N-uptake, tuber growth ceased by mid-July (70–90 kg N uptake ha^{-1}), the end of July (110–140 kg N uptake ha^{-1}), or mid-August, (140–180 kg N uptake ha^{-1}), (Möller et al., 2006). Therefore with low and moderate N –supply and when the start of late blight epidemics is relatively late (under our conditions this is mid-July) copper applications often will not increase yields (Finckh et al., 2006). However, in years with early severe late blight attacks like 2007 (the epidemic started in the beginning of June) yield losses will be generally high. Overall, yield gains through copper applications were only 5-10 % on average. The economic usefulness of copper applications needs to be scrutinised before recommending its use.

Another way to reduce copper is the use of forecasting models which optimise copper application date and amounts in relation to infection risk, crop stage, and time of the year (Musa & Forrer, 2005). In 2005-2006, without the forecasting model, copper had no significant effect on disease in plots with low nutrient availability while minimised applications combined with the forecasting model resulted in more reliable disease reductions even under low nutrient conditions. A reduction of the current maximally allowed Copper inputs from 3 kg to 1.5 kg per ha and year should thus be possible.

Other important agronomic measures like cultivar choice and seed tuber health must be emphasized to secure yields. Pre-sprouting advances aboveground crop growth by shortening pre emergence development by about 10-20 days and thus above ground crop growth duration is enhanced when late blight attacks the crops. Yield increases by 5-30 % due to pre-sprouting are consistently reported. Cultivars with early bulking behaviour will have advantages even if they are susceptible when supplied with enough nitrogen and this will be enhanced by pre sprouting of seed tubers and early planting (Böhm et al., 2001; Bruns, 2002; Kölsch et al, 1990; Haase, 2007; Möller & Reents 2007; Möller & Meinck; 2003). In addition, by pre-sprouting late blight and soft rot infested tubers will be removed, reducing early seed tuber borne infections in the field.

Besides rotational position and green manure crops, the main external fertilisers used in organic agriculture and horticulture are dry and liquid manure and compost, which are labour intensive, have variable nutrient content, and may contain pathogens and undesirable weeds. In intensive organic horticulture field and greenhouse grown crops often have deficits in nutrients. Therefore, in high value vegetable crops, more expensive fertilisers such as hair meal pellets, molasses, horn and legume meals etc. are also used in an attempt to supply nutrients more rapidly to the crops (Müller & Von Fragstein, 2005; Raupp, 2005; Kolbe, 2007). New commercial fertilisers are constantly being developed and often suppliers claim that these have additional beneficial effects especially on plant health and product quality. In addition, organic farmers can make use of products containing biological control agents and natural toxic compounds in plant extracts. These products are known as biostimulants or plant strengtheners which, for example, should enable plants to stimulate growth induce plant resistance or stimulate soil life (Brain et al.1973; Blunden, 1977; Miller, 1990; Canellas et al., 2002; Zhang & Ervin, 2004).

In chapter 3, the slow release fertilisers Biofeed Basis, Biofeed Ecomix, and BioIlsa 12,5 Export were tested in field trials with potatoes and tomatoes. Biofeed Basis (BFB) is a complex mix of plant proteins derived from seaweed, potato, maize, soybean and sesame enriched with soft ground rock phosphate, potassium sulphate and calcium carbonate. Many micro nutrients are present due to the use of seaweed. Biofeed Ecomix in addition contained some animal products for increased phosphorus supply. The manufacturer discontinued production of this product because of concerns over the use of animal derived products, however. BioIlsa 12,5 EXPORT (BI12) is an organic nitrogen fertiliser manufactured through physical hydrolysis of leather shavings of bovine hides, containing amino acids. The tested biostimulants were BioFeed Quality (BFQ) and AUSMA. BFQ is an aqueous multi-compound extract from 2 types of seaweed: *Ascophyllum nodosum* and *Fucus* spp added with 2 % dried thyme (*Thymus vulgaris*) and reinforced with humic and fulvic acids. AUSMA is an aqueous extract of pine and spruce needles.

Results indicate that mineralization of fertilizers was in time of major crop demand. This was true for potatoes with a relative short main nutrient uptake period between 2-8 weeks after crop emergence ((Harris, 1978; Marschner, 1995; van der Zaag, 1992) as well as for tomatoes which require a large amount of nutrients before initiation of the first flower truss but demand remains continuously high until the end of fruit production (Carpena et al. 1988, Jackson & Bloom, 1990 Burger & Jackson, 2003, Koivunen &. Horwath, 2005).

In the tomato trials, gross yield with tested products were at least as high as or higher than with the horn meal reference. Marketable yields were higher due to lower amounts of late blight infected fruits of the susceptible cultivar Matina or a higher number of fruits produced by the more late blight tolerant Philovita. While the differences in yields were not significant for the fertilisers alone, a combined treatment of BFB with the biostimulants BFQ and AUSMA resulted in significant yield increases, respectively. In extra laboratory experiments when inoculating detached tomato leaves *P. infestans*, susceptibility of tomatoes was reduced as well when using BFB and BI12 as fertilisers in comparison to horn meal as by treatment with BFQ and AUSMA. The effects of BFQ were independent of plant age, growth substrate or fertiliser used and Sharma et al. (2007) showed that BFQ does induce resistance in tomatoes against *P. infestans*.

Thus, it appears that the plant derived seaweed containing fertiliser BFB and the extract of several seaweed species and humic acids contained in BFQ and the biological active compounds of AUSMA were able to improve the general tomato growing conditions and plant health. Besides resistance induction, underlying mechanisms might be an increase of root development, nutrient uptake, chlorophyll content and others as was shown in several studies (Vaughan & Malcom, 1985; Whapham et al., 1993; Canellas et al., 2002; Nardi et al., 2007).

Nutrient uptake dynamics in potatoes showed that about 40 % of the nitrogen out of the fertilisers was incorporated into haulms and tubers by mid July independent of N fertilisation level. Assumption that, in addition, about 5-10 % of the nitrogen is used for roots and metabolic processes (Harris, 1978, Marschner, 1995) it can be deduced that about 45-50 % of the fertilisers was becoming plant available. This is according to Kolbe (2007) equal to the effectiveness to horn meal products and poultry manure in mineralization, but about 10 % higher than single compound plant based fertilisers.

The N mineralization efficiency of BF Basis in soil has been studied before in comparison to bone meal, chicken pellets, blood meal and horn meal in an incubation test at constant 30 ^{0}C during 6 weeks. The N-release from BFB was nearly 50 % at week 6, while it was only about 35 % for chicken-pellets and 25 to 30 % for the other biological materials (Stutterheim, 2005). In contrast, in our field trials fertilisers BFB, BI 12, and horn meal did not differ with respect to soil N supply and crop N – uptake. However, yield increase per kg applied nitrogen (YIN) differed considerably among the fertilisers. YINs of BFE, BFB and BI12 when applied in strip at 40 and 75 kg N ha^{-1} were between 90 and 159 kg ^{1} application. At an input level of 40 kg N ha^{-1} both, BFB and BI12 had significantly higher YINs than horn meal. The placement of fertilisers was also important and increased YIN significantly. In comparison, Möller and Kolbe (2003) reported that the YIN of farmyard manure in the first year is about 18-20kg per kg applied N ha^{-1}. When manure is applied continuously in the long-term, YIN increases to about 40-65kg while the YIN of liquid manure is about 59kg. Across several field trials Kolbe (2007) describes a yield surplus in potatoes when fertilised with 75 kg N ha^{-1} of 13 and 113kg per kg N-input.

The biostimulant BFQ significantly increased yield in 2005 (+6 %) and thus, YIN. This increase was independent of the other treatments. However, in 2006 no effects on yield could be observed. Many studies were done on the effect of seaweed extracts on potato yield with variable results. Several studies reported that seaweed extract stimulated haulm development and photosynthesis (Blunden & Wildgoose, 1977, Kolbe & Blau, 1998, Neuhoff, 2002) but Kolbe & Blau (1998) and Kürzinger (1995) indicated reduced tubers per plant and unaffected yields, whereas Blunden & Wildgoose (1977) as well as Neuhoff et al. (2002) reported increased tuber numbers and yields. It is likely that application management, extract formulation, production process and raw material origin and composition are influencing factors on the effectiveness of seaweed extracts in potato production.

As with tomatoes, there were some additional effects of the fertilisers and the biostimulant BFQ on potato plant health. BFB reduced common scab (caused by *Streptomyces scabies*) of tubers significantly compared to the animal derived fertilisers, however scab only played a role in 2006 and thus only assessments of 2006 are available. Thus, a final conclusion about possible scab reductions potential through the use of BFB cannot be made. However, further investigation should be conducted on that topic.

In 2005, potato black scurf (caused by *Rhizoctonia solani*) tuber infestation severity was reduced by 38 % when sprayed with BFQ. Possibly, BFQ stimulates antagonist activity, however, this was not determined. Considering the results of the compost trials reported in chapter 4, it would be extremely interesting to combine the biostimulant treatment with the compost trials.

Overall, both fertiliser products BF Basis and BioIlsa 12,5 Export performed well and can be proper alternatives to other fertiliser products used in organic systems. As demand for plant based products has increased in the wake of the BSE crisis and due to concerns of using residues derived from intensive animal husbandry particularly the plant based GMO-free BF Basis is of interest. The biostimulant BF Quality had overall positive effects on plant growth and plant health status and could be a good measure to improve crop production in organic farming.

While effects of the biostimulant on *R. Solani* in potatoes were promising, it is well known that black scurf is very much affected by the kind and stage of decomposition of organic matter. Therefore, the effects of suppressive composts on black scurf infestation were tested in additional trials reported in chapter 4.

As the pathogen is as well soil as seed tuber borne the primary means to reduce black scurf in potatoes are the use of healthy seed tubers and field hygiene. Black scurf-infested seed tubers are of importance in disseminating the disease and adding to the pool of soil-borne inoculum (Jeger et al., 1996). The effect of initial seed tuber infection on yield and disease was clearly demonstrated in our trials. Compared to healthy seed tubers initial black scurf sclerotia infestation of 2-5 and >10 % of tuber surface in untreated plots lead to a decrease in marketable yields by 14-19 and 44-66 %, an increase of black scurf severity by 8-40 and 34-86 %, respectively. Also the amount of malformed and dry core affected tubers was increased by 32-57 and 109-214 %, respectively. These results emphasize the importance of using healthy seed tubers particularly in organic potato production because of the lack of reliable control measures of seed borne inoculum. Especially the production of organic certified healthy seed tubers poses serious problems. Since the use of organic seed potatoes has become compulsory in organic potato production black scurf is increasing in importance.

Rhizoctonia solani Kühn AG-3 is as well soil as seed tuber borne. To reduce soil borne infection it is important to ensure good soil conditions with a high microbial activity with a high antagonistic potential. Soil organic matter greatly increases soil microbial activity and diversity which, in turn, are related to soil and seed borne disease suppression (Lumdsen et al., 1983, Fließbach & Mäder, 2000). While fresh organic matter promotes the saprophytic growth of *R. Solani,* well decomposed organic matter which is colonised by microbes supports antagonistic activity against the pathogen (Hoitink & Boehm, 1999). Organic matter amendments (OMA) like composted manures green yard compost (GYC) are an essential component of organic crop management. OMA improve soil structure, water holding capacity, as well as cation exchange capacity, and promotes plant growth. Some compost also suppress soil-borne plant pathogens (Hoitink & Fahy, 1986; Hoitink & Boehm, 1999). Hoitink & Böhm, (1999) stated that decomposition level of organic matter critically affects the composition of bacterial taxa and the populations and activities of biocontrol agents affecting competition, antibiosis, parasitism, and systemic induced resistance. Mature composts can serve a food base for biocontrol agents and which in turn leads to sustained biological control based on the activities of microbial communities (Hoitink & Böhm, 1999) In several studies those suppressing pathogen effects were also found by amending mature high carbon containing composts like bark and green yard composts as well as with cattle manure composts (Chung & Hoitink, 1990; Hoitink et al., 1996, Tsror et al. 2001, Bruns & Schüler 2002).

In organic farming the application of composts is limited to 5t ha^{-1}DM per year and heavy metal loads must be small to fulfil the criteria of an environmental save soil amendment. Therefore, composts must be produced in a closed and monitored collection system, accepted by the member state. The maximum allowed heavy metal concentrations in mg/kg of dry matter are: Cadmium: 0.7; copper: 70; nickel: 25; lead: 45; zinc: 200; mercury: 0.4; chromium (total): 70 (Annex II to Council Regulation (EEC) No 2092/91). However, in the studies reporting successes in suppressive effects relatively high amounts of compost were used. Thus, Tsror et al. (2001) applied $60m^3$ ha^{-1} (amounting to 15-25 t DM), while in the greenhouse studies 10-50 % compost were added to the potting mixtures (Chung & Hoitink, 1990; Hoitink et al., 1996, Bruns & Schüler, 2000).

In the present study 5t ha^{-1} DM of a yard and bio waste (60/40) compost produced in a 5 month long composting process and a 15 month old 100 % yard waste compost were used to assess the effects on potato infection with *R. Solani* when applying composts within the limits allowed. Strip and broadcast applications were compared to test, if compost effects can be optimised through application technology.

Across the differences in initial seed tuber infestation and cultivars 5t ha^{-1} DM of high quality composts incorporated in the ridge reduced the infestation of harvested potatoes with black scurf, tuber malformations and dry core tubers by 20 to 84 %, 20 to 49 % and 38 to 54 %, respectively while marketable yields were increased by 5 to 25 %. These effects were additive with the positive effects of using healthy seed tubers. Significantly reduced stem canker severity also led to higher amount of tubers per plant with compost. Clearly, strip application was superior to broadcast application as the compost concentration around the seed tubers at the particularly susceptible stages was considerably increased in that way.

The mechanisms of disease suppression were not analysed in this study. However, in other studies with suppressive composts enhanced activities of antagonistic microorganisms such *as T. harzianum, Gliocladium virens, Penicillium spp., Pseudomonas yuorescens, Bacillus cereus* and *Enterobacter cloacae* have been reported (Nelson & Hoitink, 1983; Kwok et al., 1987). It is likely that these also played a role in our trials. Suppressive composts may serve as important alternative control tools in organic as well as in conventional modern agriculture. Nevertheless, further analysis on needed compost qualities e.g. raw material composition, nutrient contents, moisture, compost age: and effectiveness in suppression with different soil conditions e.g. differences in soil borne pathogen potential, soil bulking densities climatic conditions are needed to maintain compost application as a general control measure of *R. solani* in organic potato production.

Overall, *R. solani* has a number of intrinsic properties that make its management difficult. These include a wide host range, large sclerotia insensitive to fungistasis and resistant to decomposition, rapid colonization of fresh organic matter, extensive mycelia growth, and mycelium of high biphenolic content that is relatively resistant to degradation, hyperparasitic potential, and capacity to escape soil competition under humid conditions by growing on surface organic matter (Papavizas et al, 1975, Weinhold 1977, Rickerl et al. 1995, Radtke et al. 2000). Therefore, in addition to the application of suppressive composts the management of the disease will depend on long term crop rotations (Scholte, 1992), a soil management that supports fast decomposition of plant residues by incorporating them into the soil and planting potatoes only after decomposition of fresh organic matter (Lumsden et al., 1983, Rickerl et al., 1992; Stephens et al., 1994). Early harvesting is occasionally used to escape black scurf but enhances the risk of tuber late blight infection (Dijst, 1989; Malder et al., 1992, Möller et al.2003). Reduced infection was also achieved by combining `green harvesting with the use of the hyperparasites *Verticillium bigutatum* (van den Boogert et al., 1994, 1995).

It was shown that nutrients and diseases need to be looked at together. External organic fertilisers, biostimulants and suppressive composts all have their place in organic agriculture and they do differ in their effects on plant health and nutrient dynamics and efficiency.

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Erklärung

Hiermit erkläre ich, dass ich die vorliegende Dissertation selbständig und ohne unerlaubte Hilfe angefertigt und andere als die in der Dissertation angegebenen Hilfsmittel nicht benutzt habe. Alle Stellen, die wörtlich oder sinngemäß aus veröffentlichten oder unveröffentlichten Schriften entnommen sind, habe ich als solche kenntlich gemacht. Kein Teil dieser Arbeit ist in einem anderen Promotions- oder Habilitationsverfahren verwendet worden.

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