Organic potatoes for processing

Agronomical measures and their impact upon yield and quality

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Die Disputation fand am 14. Dezember 2007 statt.

Ever tried.
Ever failed.
No matter.

Try again.
Fail again.
Fail better.

(Samuel Beckett)

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Summary

Three field experiments were conducted during 2002 and 2004 on two sites (DFH: 51°4, 9°4’, BEL: 52°2’, 8°08’) in order to examine the impact of preceding crop, pre-sprouting, N and K fertilization, and cultivar on nutrient supply, uptake and utilization, total and size graded tuber yields, as well as quality attributes of potatoes destined for processing into French fries or crisps under the conditions of organic farming. Parameters assessed were soil available nitrate-N, available K, crop N and K uptake and tuber concentration, total fresh matter (FM) and dry matter (DM) tuber yields, size-graded yields for processing into French fries, tuber DM, glucose and fructose concentration, as well as the lightness of crisps and quality attributes of French fries.

- Soil mineralized nitrate-N depended strongly on the preceding crop and the year. The level of plant available NO_3-N in 0-60 cm soil at crop emergence (end of May) was consistently highest after peas (187 and 132 kg NO_3-N ha^{-1} in 2003 and 2004, respectively), when compared with a grass legume ley (169 and 108 kg NO_3-N ha^{-1}) and cereals (112 and 107 kg NO_3-N ha^{-1}) preceding potatoes. Accordingly, total tuber FM yields were highest after peas (41.4 and 30.8 t ha^{-1} in 2003 and 2004, respectively). This also applied to tuber DM yields.
- Pre-sprouting advanced crop development and dry matter accumulation of the canopy and translocation of assimilates and N from canopy into tubers. Even though the positive response of total tuber yield to pre-sprouting by the end of July (+ 2.6 and 3.4 t ha^{-1} in 2003 and 2004, respectively) was compensated for up to final harvest in the season without any late blight epidemics (2003), but a significantly increased portion of the most-demanded tuber sizes for French fries (+ 12 % absolute of tubers >50 mm) was still found at final harvest. Average tuber weight responded consistently and positively to pre-sprouting (+ 5.4 g), cultivar (Agria) and an increased N supply (leguminous preceding crops).
- Generally, total tuber yields depended very much on the growing season. However, results indicate a strong impact of fertilization on total tuber yields and those relevant for processing. Highest FM yields (34.8 t ha^{-1} on average of 2002-2004) were obtained when an organic N source (horn grits) was applied along with mineral K (potassium sulphate). In contrast, a yield response to application of cattle manure is difficult to predict. Increasing yields after cattle manure fertilization were established only in one of three years (+5.8 t ha^{-1}), and this could be attributed to K rather than N.

- Data suggest that, when tubers are intended to be marketed for industrial processing, the choice of cultivar may be a more efficient measure to increase financial returns than fertilization.
- Overall, results show that tubers from organic potato cropping may be expected to have sufficiently high tuber DM (>19%) for processing into French fries without impairing texture of fries. Tuber DM concentration of the reference cultivar for crisps (cv. Marlen) fell short of the required minimum of 22% only when the combined N and K fertilizer was applied.
- Tuber DM concentration could be increased considerably when seed-tubers were presprouted, especially in growing seasons with a high incidence of *Phytophthora infestans* (+1.2% absolute increase). Tuber DM concentration was significantly higher after storage in two of three experiments (+0.4 and 0.5% absolute increase).
- Cultivars belonging to the very early and early maturity type showed the largest relative increase of reducing sugars (glucose and fructose) due to storage. The medium-early cv. Agria and medium-late cv. Marena proved to be best suited for processing into French fries under conditions of organic farming (limited N supply, shorter growing period), as only minor deviations from highest quality standards were established at harvest. Consistently high crisp quality was reached by medium-early cv. Marlen.
- On the whole, results show that the quality standards for tuber raw stock can be accomplished best when adequate cultivars are chosen. On the other hand, the effect of agronomical measures such as fertilization, pre-cropping and seed-tuber preparation may be rather small and response of internal tuber quality and quality of fried products is difficult to predict.

Zusammenfassung

Drei Feldversuche auf zwei Standorten (DFH: 51°4, 9°4', BEL: 52°2', 8°08') wurden in den Jahren 2002 bis 2004 durchgeführt, um den Einfluss der Vorfrucht, des Vorkeimens, der N- und K-Düngung und der Sorte auf Nährstoffverfügbarkeit, Gesamt- und sortierte Knollenerträge sowie die Qualität von Kartoffeln und deren Eignung für die industrielle Verarbeitung zu Pommes frites und Chips zu untersuchen.

Besimmt wurden die N- und K-Verfügbarkeit im Boden, die N- und K-Aufnahme von Kraut und Knollen, gesamte Frisch- und Trockenmasseerträge, sortierte Frischmasseerträge für die Verarbeitung, sowie die Gehalte der Knollen an Trockensubstanz und reduzierenden Zuckern. In einer sensorischen Prüfung wurden Qualitätsparameter von Pommes frites (Aussehen/Farbe, Textur und Geschmack/Geruch) bewertet, die gewichtet in einen Qualitätsindex eingingen. Die Qualität der Chips wurde maschinell durch den L-Wert (Helligkeit) des Produktes quantifiziert.

- Der Gehalt des Bodens an mineralisiertem Nitrat-Stickstoff hing von der Vorfrucht und dem Jahr ab. Nach Erbsen wurden zum Auflaufen der Kartoffeln in den Versuchsjahren 2003 und 2004 (187 und 132 kg NO_3-N ha^{-1}) die höchsten NO_3-N-Werte in 0-60 cm Boden gemessen verglichen mit Kleegras (169 bzw. 108 kg NO_3-N ha^{-1} oder Getreide (112 kg bzw. 97 kg NO_3-N ha^{-1}), obgleich die Differenz nicht in allen Fällen signifikant war. Entsprechend wurden nach Erbsen die höchsten Knollen-Frischmasseerträge (414 und 308 dt ha^{-1}) geerntet. Dasselbe galt für die Trockenmasserträge, was belegt, dass der Trockensubstanzgehalt der Knollen bei verbesserter N-Versorgung nicht im selben Maße sinkt, wie der Frischmasseertrag steigt.
- Das Vorkeimen der Pflanzknollen führte zu einer rascheren phänologischen Entwicklung im Jugendstadium der Pflanze, beschleunigter Trockenmassebildung des Krautes und einer früheren Einlagerung von Assimilaten vom Kraut in die Knollen. Obwohl die positive Wirkung des Vorkeimens auf den Gesamtertrag bis Ende Juli (+ 26 in 2003 bzw. 34 dt ha^{-1} in 2004) im Jahr ohne Krautfäuleepidemie von den nicht vorgekeimten Varianten bis zur Endernte im September kompensiert wurde, konnte in diesem Jahr durch Vorkeimen dennoch ein erhöhter Ertragsanteil (+ 12%) der besonders nachgefragten Übergrößen (>50 mm für Pommes frites) erzielt werden. Die durchschnittliche Knollenmasse reagierte positiv auf Vorkeimen (+ 5,4 g), Sortenwahl (Sorte Agria) und ein erhöhtes N-Angebot (Leguminosenvorfrucht).

- Generell wurde deutlich, dass die Knollengesamterträge unter den Bedingungen des Ökologischen Landbaus (geringe bis mittlere Nährstoffversorgung, verkürzte Vegetationsdauer) sehr stark vom Anbaujahr abhängen. Die Ergebnisse belegen jedoch, dass organisch-mineralische N-K-Düngung den sortierten Ertrag an Knollen für die Verarbeitung signifikant erhöht: Höchste Gesamt- und sortierte Knollenfrischmasseerträge wurden nach kombinierter N (Horngrieß) und mineralischer K- (Kaliumsulfat) Gabe erzielt (348 dt ha^{-1} im Durchschnitt von 2002-2004). Im Gegensatz dazu kann eine Wirkung von Stallmist auf den Ertrag im Jahr der Ausbringung nicht unbedingt erwartet werden. Steigende Erträge nach Stallmistdüngung wurden lediglich in einem von drei Versuchsjahren (+58 dt ha^{-1}) festgestellt und ließen sich eher auf eine K- als eine N-Wirkung zurückführen.
- Die Ergebnisse belegen, dass die Sortenwahl eine entscheidende Rolle spielt, wenn die Kartoffeln für die industrielle Verarbeitung zu den oben genannten Produkten angebaut werden. Insgesamt kann festgestellt werden, dass Kartoffelknollen aus ökologischen Anbauverfahren ausreichend hohe Trockensubstanzgehalte aufweisen, um für die Verarbeitung zu Pommes frites (>19%) geeignet zu sein und ohne dass dadurch die Konsistenz des Endproduktes gefährdet würde. Der Trockensubstanzgehalt der Referenzsorte für Chips, „Marlen“, unterschritt das in der Literatur geforderte Minimum für Chips von 23% lediglich, wenn die kombinierte Horngrieß-Kaliumsulfatdüngung zur Anwendung kam.
- Die Trockensubstanzgehalte der Knollen konnten durch Vorkeimen signifikant gesteigert werden und der Effekt war besonders groß (+1.2% absolut) in dem Jahr mit frühem Auftreten der Krautfäule (*Phytophthora infestans*), d.h. verkürzter Vegetationszeit. Die Knollen-Trockensubstanzgehalte waren in zwei von drei Experimenten nach Lagerung höher (+0.4 und 0.5% absolut) als noch zur Ernte.
- Sorten der sehr frühen und frühen Reifegruppe wiesen den größten relativen Anstieg der Gehalte an reduzierenden Zuckern (Glukose und Fruktose) während der Lagerung auf. Den mittelfrühen Sorten „Agria“ und „Marena“ hingegen kann aufgrund des von ihnen erreichten höchsten Qualitätsstandards (Pommes frites) zur Ernte eine sehr gute Eignung für die Bedingungen des Ökologischen Landbaus unterstellt werden. Die durchgehend beste Chipseignung wies die mittelfrühe Referenzsorte „Marlen“ auf.
- Insgesamt konnte nachgewiesen werden, dass durch gezielte Sortenwahl der Trockensubstanzgehalt und die Konzentration reduzierender Zucker, sowie die

Qualität der Endprodukte (Pommes frites und Chips) gezielt beeinflusst werden kann. Im Gegensatz dazu haben acker- und pflanzenbauliche Maßnahmen wie Düngung, Wahl der Vorfrucht und Vorkeimen der Pflanzknollen einen eher geringen Einfluss. Dementsprechend sollte der Landwirt versuchen, durch die Wahl der Sorte den hohen Anforderungen der Industrie an die Rohware gerecht zu werden.

1 Introduction

The potato plays an important role in organic farming systems, both agronomically and economically (Dreyer and Padel, 1992; Redelberger, 2004). In many European countries, the area of organic potato cultivation has been increasing over the past years. Among other crops, potato is one of the most highly demanded products on the market for organic produce (Tamm et al., 2004). Organic cultivation of potatoes for industrial processing into French fries or crisps may be a new source of income and is already practised by organic farmers in some European countries (Sylvander and Le Floc'h-Wadel, 2000). An economically successful marketing of potatoes for processing requires the fulfilment of certain quality standards, which differ considerably from those set for table potatoes (Storey and Davies, 1992). High portions of larger tubers are required for French fries, but also for crisps (Schuhmann, 1999; Böhm et al., 2002). Besides, there are ranges and thresholds for tuber dry matter (DM), as well as for the concentration of reducing sugars (glucose and fructose) within tuber fresh matter (Kolbe, 1995; Putz and Lindhauer, 1994). Tubers should not only meet these standards shortly after harvest, but also after storage (Schuhmann, 1999). Hence, at harvest, tubers need to have reached a state of maturity that allows several months of storage before further processing (Kumar et al., 2004). Until recently, hardly any published data were available on the management of organic potato crops destined for industrial processing (Böhm et al., 2002).

Tuber size is mainly determined by N, which affects the length of the tuber bulking period and tuber bulking rate (Millard and MacKerron, 1986; Möller, 2002; Finckh et al., 2006), but also by cultivar (Böhm et al., 2002; Möller, 2003). Tuber yield response is mainly dependent on the rate at which nitrogen is released from preceding crops (Stockdale et al., 1992; Köpke, 1995; van Delden, 2001) or organic amendments such as animal manures or green manure crops (Schmidt et al., 1999; Neuhoff and Köpke, 2002). Pre-sprouting of seed-tubers was found to increase tuber yield under conditions of organic farming (Karalus and Rauber, 1997), even though response seems to be dependent upon the cultivar used (Allen et al., 1992; Eremeev et al., 2003). Little is known about the potential interactions between N supply and crop growth as a function of seed-tuber preparation.

Potato crops also have a large demand for potassium (K), which is known to have an impact upon quality parameters, such as reducing sugars and dry matter as well as on the quality of the processed potato (Stanley and Jewell, 1989; Rogozińska and Pińska, 1991; Allison et al., 2001). The rate of mineral K application in conventional cropping systems is usually based on the optimal N rate and not on K requirements (Neuhoff and Köpke, 2002; Thybo et al., 2001, Öborn et al., 2005). Stein-Bachinger and Werner (1997) stated that N from farmyard manure is usually not readily available in the season of application. Spiess et al. (1995) reported that K content of tubers can be increased by application of farmyard manure. However, organic fertilizer is very limited, and stockless organic farms may be inclined to fall back on mineral sources of K if organic manure is not available. Their use is permitted only where the need can be demonstrated to the certifying body, e.g. by soil analysis or by presentation of a nutrient budget (Watson et al., 2002). On the other hand, the use of mineral K is not consistent with the philosophy underlying the organic agriculture movement and the regulations of some organic farming associations (e.g. *Demeter*). Hence, it seemed appropriate to examine different sources of N and K in terms of their suitability for organic potato nutrition when tubers are destined for processing.

The aim of the present thesis is to evaluate different agronomic measures which are intrinsic to organic potato cropping systems in terms of their impact upon total fresh matter and DM tuber yield, marketable (size-graded) tuber yield, internal quality attributes relevant for processing tuber DM and reducing sugar concentration, and the quality of the finished French fries and crisps. The thesis is divided into five chapters. The following chapters 2-4 comprise three manuscripts submitted to international peer-reviewed journals. Chapter 2 contains a study on the effect of different N and K sources on plant N and K availability, nutrient use, and tuber yield of potatoes destined for processing (*European Journal of Agronomy 26, 187-197*). Chapter 3 comprises the experiments on the effect and interaction of preceding crop and pre-sprouting on N availability, uptake and use, as well as total and graded tuber yields (*Journal of Agronomy and Crop Science 2007, 193, 270-291*). Chapter 4 deals with the impact of the agronomical treatments examined in the experiments (chapters 2 and 3) and from a cultivar trial on tuber DM and reducing sugar concentrations, as well as quality of the finished product (French fries and crisps) both at harvest and after storage (*Potato Research 2007, in press*). Finally, chapter 5 unites the main and new achievements of the three studies in a synoptic discussion.

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2 The effect of different N and K sources on tuber nutrient uptake, total and graded yield of potatoes (*Solanum tuberosum* L.) for processing

European Journal of Agronomy (2007) 26, 187-197

Abstract

A field experiment was conducted for three consecutive years (2002-2004) on loamy sand on an organically managed farm near Osnabrück, Germany. Four replicates of four fertilizer treatments and a control were established annually in a split plot design for two maincrop potato cultivars (*Solanum tuberosum* L. cv. Agria and cv. Marlen). The application of fertilizers followed a soil test of available potassium at the onset of vegetation. Fertilizer treatments were deep litter cattle manure, potassium sulphate (40% K), potassium sulphate+horn grits (14% N) and horn grits, all supplying equivalent quantities of K (175–215 kg ha^{-1}) and/or N (100–145 kg ha^{-1}) respectively, and a control with no fertilization. Deep litter cattle manure was analysed for total N, K and other elements and - just as the other fertilizers - applied in spring just before ploughing. Soil content of NO_3-N was determined from samples taken at defined growth stages of the potato crop. Furthermore, total and graded tuber yields, tuber concentration as well as uptake and concentration of N and K were assessed.

Results of soil nitrate-N content confirmed that organic cropping systems are dominantly nitrogen limited and this is likely to affect crop utilization of K. Available K content of soil and K in tuber dry matter could be increased through application of either cattle manure or potassium sulphate.

Total yields depended strongly on the individual year and varied between 27.9 and 35.3 t ha^{-1} (cv. Agria). Results indicate a strong influence of fertilizer treatment on total tuber yields and those relevant for processing into crisps (40-65 mm) or French fries (proportion of tubers >50 mm in yield >35 mm). Highest yields were obtained after application of the combined mineral K (potassium sulphate) and organic N (horn grits) source. The response of tuber yield to cattle manure was not consistent over the growing seasons, which confirms that cattle manure is generally a very insecure source of plant available N in the year of application. Possibly, the positive yield response in 2004 was due to K rather than N, since only tuber K concentration and uptake were significantly affected. Overall, the results suggest that in organic potato cropping the correlation between available K - as determined with the common soil test procedures - and yield response may be low. Response of tuber yields graded for crisps production confirmed that cultivars have to be chosen carefully to secure adequate tuber yield of the required size grades.

Keywords: Potato; Potassium; Nitrogen; Mineral Fertilizer; Manure; Organic Agriculture; Yield; Processing

2.1 Introduction

The potato crop (*Solanum tuberosum* L.) plays an important agronomic and economic role for the majority of organic farms in Western Europe. Organic cultivation of potato raw stock for industrial processing into French fries or crisps may be a new source of income and is currently practised by organic farmers in European countries, where demand for organic products is strong and still growing (Sylvander and Le Floc'h-Wadel, 2000). Until recently, research on organic potatoes focused exclusively on the table potato (Karalus and Rauber, 1997; Thybo et al., 2001; Neuhoff and Köpke, 2002; Roinila et al., 2003; Wszelaki et al., 2005).

The potato processing industry sets high quality standards, and organic potato growers have to compete with conventional famers' expertise in cultivating potato raw stock for processing. In Germany, the industry processing organic potatoes into French fries demands tubers graded >50 mm for French fries and 40-65 mm for crisps. However, in organic farming, a high nitrogen (N) supply required to obtain high yields of larger tubers is difficult to ensure. Grass / clover leys supply high amounts of N in organic matter, but N mineralization from residues is hard to synchronize with crop demand (Heß, 1989; Pang and Letey, 2000; van Delden, 2001). Thus, an alternative means in organic crop nutrition is the use of organic amendments, such as cattle manure (Köpke, 1995; Stein-Bachinger and Werner, 1997). Previous research revealed only insignificant yield response of organic potatoes to composted cattle manure (Matthies, 1991; Stein-Bachinger and Werner, 1997), and some authors have reported increased levels of tuber K concentration (Böhm and Dewes, 1997; Neuhoff and Köpke, 2002) which was found to improve quality of tubers destined for processing (Stanley and Jewell, 1989). Even in stocked organic crop rotations, organic fertilizer is very limited. Stockless organic farms may be inclined to fall back on mineral sources of K if organic manure is not available. Routinely, when soils are tested low for K, organic farmers' consultants in Germany recommend supplemental use of mineral K fertilizers to organic potato growers. Yet, the principles of organic farming require that K fertilizers can be used for soil fertilization and conditioning only to the extent that an adequate nutrition of the crop is not possible through the recycling of organic materials alone. Previous research has concentrated on the response of crops to K fertilizer in the presence of adequate / high levels of available N (Stanley and Jewell, 1989; Rogozińska and Pińska, 1991; Allison et al., 2001). In organic agriculture, where N is usually very limited, the correlation between available K and crop response to K application may even be lower than in conventional cropping systems.

In this study, the following questions were to be answered: (i) What is the effect of fresh deep litter cattle manure on nutrient availability, N and K uptake, concentration, as well as total and graded yield of tubers for processing? (ii) Is the combined application of a mineral K and an organic N source an alternative to cattle manure? (iii) Can the effect of mineral K fertilizer be compensated by cattle manure? (iv) How strong is the impact of the cultivar compared to the effect of fertilizer application?

Results of a two factorial experiment from three successive years (2002-2004) are presented.

2.2 Material and Methods

2.2.1 Experimental site and general conditions

The study was conducted under field conditions on an organic farm near Osnabrück, Germany (52°2'N, 8°8'E). The farm has been managed organically since 1984. It is located 90 m above sea level with a total annual rainfall of 856 mm and a mean annual air temperature of 9.1 °C (1960-1990) according to the Deutscher Wetterdienst (Anonymous, 2005). Soil texture in each year was loamy sand (65% sand; 25% silt; 10% clay), soil type a Haplic Luvisol.

2.2.2 Treatments and management

The field experiment was set up in a split-plot design (main plot factor: fertilizer; sub-plot-factor: cultivar). The trial covered five (fertilizer; F) times two (cultivar; CV) treatments, with four replications. Fertilizer treaments were fresh deep litter cattle manure (CM) from suckler cows, potassium sulphate (PS; 40% K), potassium sulphate + horn grits (PSHG; 14% N), horn grits (HG) and an unfertilized control (CON). Cultivars used were Agria and Marlen, both mid-early maincrop cultivars tested suitable for organic cultivation of tubers for processing into French fries (cv. Agria) and crisps (cv. Agria and Marlen) in previous field experiments (Böhm et al., 2002). CM served as a reference fertilizer for K and N. Thus, in each year, the rates of K and N applied with PS and HG, respectively, were equivalent to those of CM (Table 2.1). Catch crops (2002 and 2004) and preceding crops (2003) were incorporated with a rotary cultivator just before -and ploughed in- immediately after fertilizer application. Seed tubers were graded 40-50 mm and pre-sprouted, keeping two to three tuber layers in boxes (600*400*190 mm; Bekuplast, Ringe, Germany) illuminated at 20 °C for three days and at 10-15 °C for the subsequent 5-6 weeks. Seed was planted with a two-row planter 34 cm and rows 75 cm apart, at a depth of 8-10 cm.

Table 2.1: Soil, experimental and crop management details

	2002	2003	2004
Soil sampling	4 April 2002	11 April 2003	7 April 2004
Days before planting	18	11	13
pH ($CaCl_2$)	5.8 ± 0.10[a]	5.6 ± 0.02	5.7 ±0.13
P (CAL) (mg kg^{-1}; 0-30cm)	44 ± 2.2	53 ± 21.2	42 ± 8.0
K (CAL) (mg kg^{-1}; 0-30cm)	80 ± 5.6	126 ± 23.3	76 ± 24.3
Mg ($CaCl_2$) (mg kg^{-1}; 0-30cm)	50 ± 3.2	54 ± 7.4	35 ± 3.5
NO_3-N (kg ha^{-1}; 0-60 cm)	21 ± 2.9	59 ± 3.6	12 ± 1.9
Preceding crop	*Triticum spelta* L.[b]	Grass clover (*Lolium perenne* L. and *Trifolium pratense* L)[c]	*Triticum aestivum* L.[d]
CM [d] (sampling date)	28 March 2002	2 April 2003	23 March 2004
% DM	25.0 ± 0.57	33.4 ± 3.32	17.7 ± 0.92
N (kg t^{-1} DM)	15.1 ± 0.94	13.0 ± 2.21	20.6 ± 1.02
P (kg t^{-1} DM)	3.6 ± 0.25	3.2 ± 0.56	5.5 ± 0.19
K (kg t^{-1} DM)	27.4 ± 2.92	17.3 ± 3.50	30.9 ± 5.72
C to N ratio	34 ± 2.2	24 ± 2.31	19 ± 0.9
Date of fertilization	4 April 2002	11 April 2003	14 April 2004
Nutrients applied by CM[e]			
N (kg ha^{-1})	106	130	146
P (kg ha^{-1})	25	32	39
K (kg ha^{-1})	192	175	217
CM [e] fresh wt. (t ha^{-1})	28	30	40
Date of planting	22 April 2002	22 April 2003	20 April 2004
Main plot size (m x m)	10.5 x 9.6	10.5 x 9.6	10.5 x 9.6
Sub plot size (m x m)	4.5 x 5.4	4.5 x 5.4	4.5 x 5.4
Harrowing and hilling	14 April, 21 May and 11 June 2002	4 June and 28 May 2003	10 May and 6 June 2004
Manual weeding	03 June 2002	27 May 2003	19 May and 3 June 2004
Growth stage at soil sampling	Day of sampling (days after planting)		
BBCH 09[f]	27 May 2002 (35)	27 May 2003 (35)	12 May 2004 (22)
BBCH 59[f]	20 June 2002 (59)	20 June 2003 (59)	26 June 2004 (57)
BBCH 69[f]	11 July 2002 (80)	10 July 2003 (79)	19 July 2004 (80)
BBCC 99[f]	10 September 2002 (140)	4 September 2003 (135)	4 September 2004 (126)

[a] Means ± standard deviation

[b] Catch crop (*Lolium perenne* L. + *Trifolium pratense* L.) undersown in dinkel (*Triticum spelta* L.)

[c] Grass clover undersown in cereals in 2001, and mulched 3 x in 2002

[d] Catch crop (*Trifolium incarnatum* and *Raphanus sativus* L.) undersown in wheat (*Triticum aestivum* L.)

[e] CM: cattle manure

[f] BBCH 09 = crop emergence; BBCH 59 = start of flowering; BBCH 69 = end of flowering; BBCH 99 = mature crop (after Hack et al., 1993).

2.2.3 Measurements and observations

Daily weather data and the long–term average (1960-1990) were obtained from a station 7.7 km from the experimental fields for the three cropping seasons (Anonymous, 2005). Precipitation from March to August in 2002 (427 mm) and 2004 (432 mm) was consistent with the 30-year average (426 mm), but only 285 mm were recorded in 2003. Higher total precipitation was recorded in July 2002 (103 mm) and 2004 (114 mm), compared to 2003 (80 mm). A pronounced deviation from the long-term monthly average daily temperature was measured from June to August in 2003 (Table 2.2).

At BBCH 69, leaves and stems (and tubers) of 12 plants per plot (cv. Agria only) were sampled in order to determine nitrogen and potassium concentration of the canopy. The sampling in 2004 failed due to the early incidence of late blight. Individual sub-plots for harvest at maturity (BBCH 99) contained 6 rows, with 16 plants per row, each 5.4 m long (Table 2.1). The inner four rows were lifted with a one-row harvester and picked up by hand. Tubers were weighed, counted and graded (>35, >50 and 40-65 mm) to assess tuber yield relevant for processing. Late blight was assessed weekly as percent diseased leaf area following the scheme given by James (1971).

2.2.4 Laboratory analysis

In order to determine selected chemical properties of CM, 7 representative samples of fresh material (5 l each) were weighed before and after drying (70 °C for 2.5 days) and subsequently ground (0.5 mm) with a Pulverisette No.19 laboratory cutting mill (Fritsch, Idar-Oberstein, Germany). Sub-samples of 1g (4 decimal places) were dry-ashed in a muffle oven at 550 °C for 8 hrs and, before weighing, kept inside a desiccator to cool down and stay dry. Subsequently, HCl (32%) was added and the solution left overnight. After transfer into a retort made up to 100 ml with distilled H_2O, samples were passed through a 615¼ filter (Macherey and Nagel, Düren, Germany) and transferred into 100 ml polyethene bottles. Total phosphorus (P) was measured with a UV-1602 spectro-photometer (Shimazu Co., Kyoto, Japan) at 580 nm against water. Total potassium (K) was measured with an ATI Unicam 939 atomic absorption spectrometer (Colchester, U.K.). Total N was determined using a Macro N auto-analyzer (Elementar Analysesysteme, Hanau, Germany).

Table 2.2: Rainfall (mm/month) and average daily temperature (°C) at the experimental site during 2002-2004

	Long-term mean (1960-1990)		Departure from long-term mean					
			2002		2003		2004	
	mm/month	°C	mm/month	°C	mm/month	°C	mm/month	°C
Jan	78	1.2	-1	2.4	24	0.2	9	0.9
Feb	55	1.7	85	4.6	-28	-1.6	13	2.0
Mar	69	4.5	-25	1.8	-40	2.4	-23	0.7
Apr	57	8.0	4	0.8	3	1.3	-14	2.1
May	68	12.6	-38	1.3	-5	1.1	-16	-0.6
Jun	86	15.7	-17	1.3	-65	2.8	-17	-0.3
Jul	74	17.1	29	0.4	6	1.9	40	-0.5
Aug	71	16.9	48	2.3	-40	3.5	36	2.1
Sep	67	13.9	0	0.4	18	0.5	0	0.9
Oct	63	10.0	53	-1.5	-7	-3.8	-17	1.0
Nov	79	5.3	0	1.5	-36	2.2	18	-0.2
Dec	88	2.4	-27	-1.6	-2	0.8	-21	0.2
Mean	856	9.8	112	0.4	-172	0.3	7	0.0

N and K concentration in DM of tubers was assessed from a sub-sample of 20 tubers (graded >40 mm) from each plot. Tubers were cut into cubes of 1 cm^3 with a Dito TRS vegetable cutter (Dito Electrolux Co., Herborn, Germany). The DM content was calculated by weighing before and after drying at 70 °C for 24 hrs. Immediately after drying, sub-samples were ground (0.5 mm) and stored in a dry, cool and dark place until further analysis**.** Total tuber DM was determined from the tuber fresh weight ($t\ ha^{-1}$) multiplied by tuber DM concentration (%) divided by one hundred. N and K uptake of tubers was calculated by multiplying N or K concentration by tuber DM. Canopy N and K concentration was determined from a sub-sample of the whole canopy sampled from 12 plants per plot at BBCH 69 after drying, grinding and the according N and K analysis described for tubers.

Soil samples were taken at defined phenological growth stages (Hack et al., 1993) of the potato crop (Table 2.1). NO_3-N was determined using 1% K_2SO_4 as an extractant according to the method described in VDLUFA (1991). Available P, K and Mg were determined at 0-30 and 30-60 cm according to Schüller (1969). P and K were extracted in a solution of calcium-acetate-lactate (CAL). P was measured photometrically at 580 nm as a complex with molybdenum and K by atomic absoption spectro-photometry at 767 nm. Mg was extracted with 0.0125 M calcium chloride ($CaCl_2$), the solution shaken for 2 hrs, 0.1 ml Schinkel solution added, and Mg measured by atomic absorption spectrometry. Soil pH was determined from a solution of 20 g soil (+50 ml of 0.01 M $CaCl_2$) - after shaking for 0.5 hrs and leaving the solution over night - with a Titran Line alpha TM pH meter (Schott Instruments, Mainz, Germany).

2.2.5 Statistical analysis

The experiment was conducted using four blocks (BL). Each block was divided into five main plot units, and five different fertilizer (F) treatments (including a control) were randomly assigned to them. Two cultivars (CV) were randomly assigned to subplot units within each main plot. Randomization of both main plot and subplot was done by PROC PLAN in SAS (SAS Institute, 1999).

Data obtained in this study were subjected to statistical analysis in SAS (9.3). Before applying a mixed model (Piepho et al., 2003), data were tested for normality of residuals with a Shapiro-Wilk test using PROC UNIVARIATE. A test for homogeneity of variance of the residuals (heteroscedasticity) was conducted using the option HOVTEST in PROC GLM at the main factor level in order to obtain a modified Levene test after Brown and Forsythe (1974). Determination of the correct degrees of freedom for every estimate and test of interest was done by the Satterthwaite option, which controls the computation of degrees of freedom for the test of fixed effects and for the LSMEANS statement. Fisher’s least significant difference was given by multiplying the standard error of a difference by t, where t is a critical value from a t-distribution with appropriate degrees of freedom. Additionally, a Dunnett test was calculated for stronger comparisons between the unfertilized control and each of the four fertilizer treatments. The dependent variables N and K uptake and concentration, as well as total and graded tuber yields were analyzed by fitting a mixed model. F, CV, Y (year) and BL were considered as fixed effects and BL•F•Y as residual random error (Piepho et al., 2003). Soil samples were taken on the main plot level (representative sample of both sub factor treatments), since the effect of cultivar on soil nutrient content was considered to be negligible. When analysing the main plot factor effect (here: fertilizer) in a split-plot experiment, data were treated like those from a completely randomized block design (Piepho et al., 2003). Thus, response of plant available K and NO_3-N was done applying a general linear model (PROC GLM), years being analysed separately. The same applied for N and K concentrations of the canopy (cv. Agria) at BBCH 69.

2.3 Results

Chemical properties of the material varied appreciably over the years. Due to the varying K to N ratios in CM and the different rates of K applied in individual years, the rate of applied N differed between the growing seasons (Table 2.1). Hence, the amount of fresh CM applied varied between 28 (2002) and 40 t ha^{-1} fresh wt. (2004), in order to supply high rates of K (178-217 kg K ha^{-1}).

In July and August 2002, the warm and moist weather conditions (Table 2.2) were beneficial to late blight epidemics and in early August the canopy had been destroyed by the fungus *Phytophthora infestans*. In contrast, the dry and warm weather during June and August 2003 prevented the epidemic spread of the disease but resulted in modest wilting and slow senescence of the canopy. A moderate development of the fungus was recorded in 2004, starting in mid July, gradually leading to premature death of the canopy not until the end of August (data not shown).

2.3.1 Mineralized N and available K

The overall level of NO_3-N at 0-60 cm soil was strongly dependent on the individual year (Table 2.1). On the day of fertilizer application, it varied between 12 (after cereals in 2004) and 59 kg ha^{-1} (after grass / clover in 2003). Highest values at BBCH 09 (161 kg NO_3-N ha^{-1}) were measured in 2003, while in 2002 and 2004 less nitrate-N was provided by crop residues (95 and 107 kg NO_3-N ha^{-1}). Accordingly, at BBCH 99 highest soil contents were found in 2003 (94 kg NO_3-N ha^{-1}) and very low levels in 2002 and 2004 (35 and 33 kg NO_3-N ha^{-1}). Significantly highest contents were found when N had been applied via horn grits (PSHG and HG, respectively) in soil sampled at BBCH 09, 59 and 69. Cattle manure (CM), on the other hand, did not increase nitrate-N at any measurement (Fig. 2.1a–c).

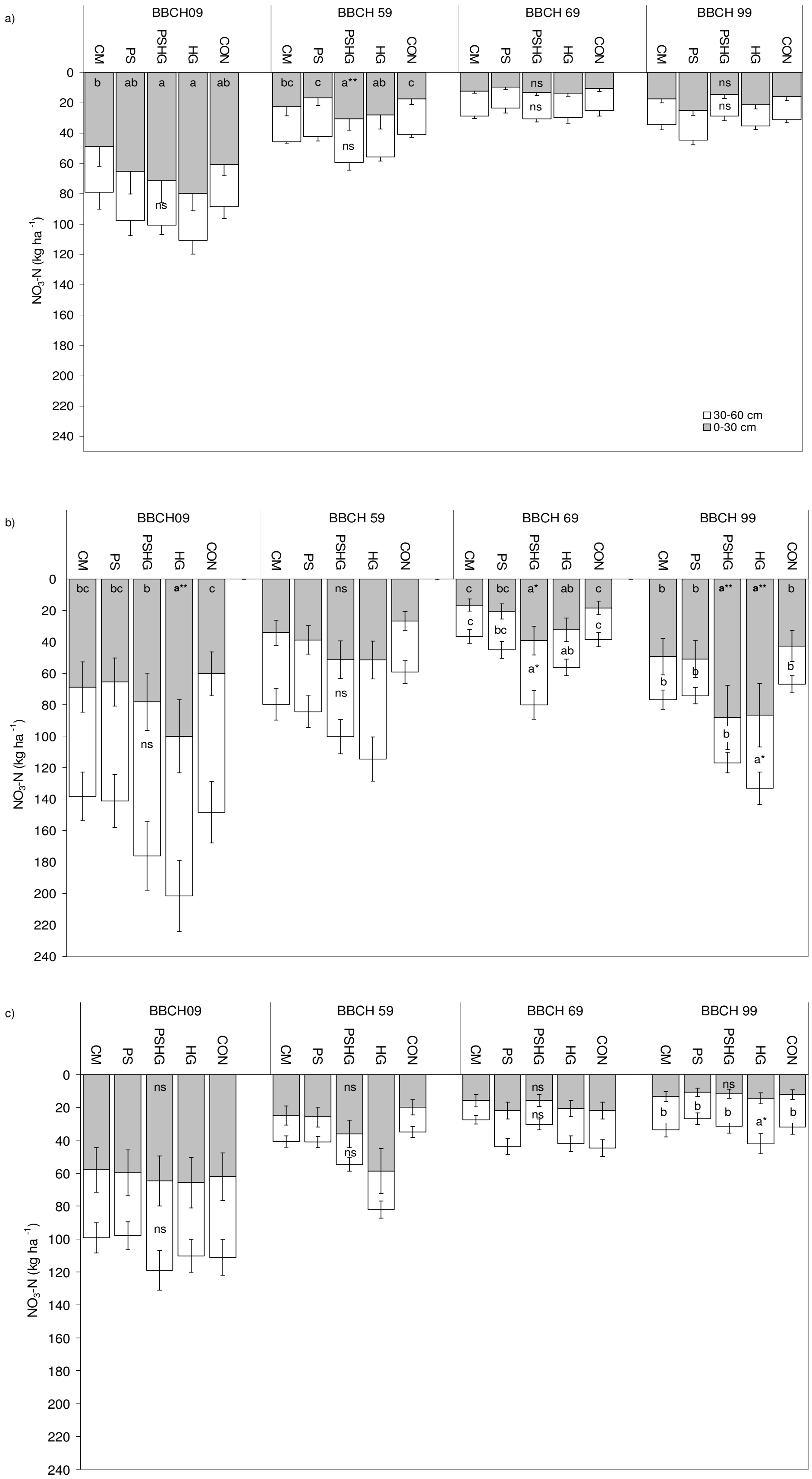

Figure 2.1: Mineralized NO_3–N in soil (0–30 and 30–60 cm) as affected by fertilization at different growth stages in a) 2002, b) 2003 and c) 2004; means ± SD.

In Figure 2.1, different lower case letters denote significant differences between fertilizer treatments (t-test at $p<0.05$). Asterisks denote significant differences between a fertilizer treatment and CON at $p<0.05$ (*); $p<0.01$ (**) and $p<0.001$ (***), while *ns* means *not significant*,

Values for available K in topsoil (0-30 cm) at fertilization varied over the years, with highest K contents in 2003 (126 mg kg^{-1}) compared to 2002 (80 mg kg^{-1}) and 2004 (76 mg kg^{-1}) (Table 2.1). At crop emergence, fertilizer application had a significant effect on available K only in one year (2002), when highest values were measured after CM (142 mg kg^{-1}) and PS (132 mg kg^{-1}), both being significantly higher ($p<0.05$) than in the CON plots (93 mg kg^{-1}) (Table 2.3).

Table 2.3: Concentrations of (CAL) available K (mg kg^{-1} soil) in 0-30 cm soil as affected by fertilization in (a) 2002, (b) 2003 and (c) 2004; means ± SD

	(a) 2002		(b) 2003		(c) 2004	
CM	142 ± 20.3	a*	122 ± 3.2	ns	111 ± 40.9	ns
PS	132 ± 27.9	ab*	120 ± 11.9		99 ± 40.2	
PSHG	118 ± 14.6	abc	130 ± 18.0		131 ± 16.6	
HG	106 ± 5.4	bc	121 ± 14.5		88 ± 26.9	
CON	93 ± 9.8	c	108 ± 29.2		90 ± 24.3	
Mean	118		120		104	
LSD (5%)	29					

Different lower case letters represent significant differences between fertilizer treatments (t-test at $p<0.05$); asterisks denote significant differences between a fertilizer treatment and CON at $p < 0.05$ (*); $p < 0.01$ (**) and $p < 0.001$ (***); ns = not significant.

2.3.2 N and K concentration in canopy at BBCH 69

N and K concentrations of canopy (leaves and stems) DM (cv. Agria) at BBCH 69 were significantly affected by fertilization and year, both interacting significantly for K concentration. While the N content of the canopy was much higher in 2002 compared with 2003, the opposite was true for canopy K concentration. It was horn grits application that consistently caused a significantly increased N concentration. For K in canopy DM, highest values were measured after CM (2002) and PSHG (2003). Over the two growing seasons, values for N ranged between 40.9 and 50.7 g kg^{-1} and for K between 29.0 and 40.0 g kg^{-1} (Table 2.4).

Table 2.4: N and K concentration in canopy DM (g kg^{-1}) at BBCH 69 as affected by fertilization (cv. Agria); means ± SD

N in canopy DM (g kg^{-1})		
	2002	2003
CM	46.6 ± 1.65 c	35.2 ± 3.34 c
PS	49.8 ± 2.31 bc	37.4 ± 4.15 c
PSHG	56.3 ± 2.68 a	43.0 ± 2.50 b*
HG	54.2 ± 2.70 a	47.2 ± 2.03 a***
CON	53.3 ± 2.24 ab	38.0 ± 2.33 c
Mean	52.0	40.1
LSD (5%)	4.03	4.80

K in canopy DM (g kg^{-1})		
	2002	2003
CM	35.6 ± 1.26 a***	44.4 ± 2.96 b
PS	29.9 ± 1.39 b***	47.0 ± 5.03 b*
PSHG	23.0 ± 1.09 c	55.2 ± 4.69 a***
HG	28.4 ± 1.42 b**	41.8 ± 3.76 bc
CON	21.0 ± 0.88 d	37.0 ± 3.71 c
Mean	27.6	45.1
LSD (5%)	2.10	5.99

Different lower case letters represent significant differences between fertilizer treatments (t-test at p <0.05); asterisks denote significant differences between a fertilizer treatment and CON at $p < 0.05$ (*); $p < 0.01$ (**) and $p < 0.001$ (***); ns = not significant.

Table 2.5 shows the results of the analysis of fixed effects for the parameters discussed in this paper, except for CAL-extractable K and N, as well as K concentration of the canopy at BBCH 69.

Table 2.5: Test of fixed effects: *P*-values for treatment effects F (fertilization) CV (cultivar), Y (year), their interactions and BL (block)

			Tuber N uptake (kg N ha^{-1})		Tuber K uptake (kg K ha^{-1})		Tuber N concentration (g kg^{-1})		Tuber K concentration (g kg^{-1})	
Effect	Numerator d.f.	Denominator d.f.	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value
F	4	42	29.2	**<.0001**	9.9	**<.0001**	30.0	**<.0001**	17.1	**<.0001**
CV	1	45	6.8	**0.0126**	18.0	**0.0001**	0.9	0.337	0.7	0.3961
Y	2	42	80.7	**<.0001**	12.0	**<.0001**	48.8	**<.0001**	32.0	**<.0001**
F x CV	4	45	1.5	0.2123	0.8	0.5648	1.0	0.4157	8.6	**<.0001**
F x Y	8	42	1.4	0.2094	1.7	0.1166	1.0	0.4824	2.6	**0.0224**
CV x Y	2	45	3.6	**0.0341**	9.7	**0.0003**	0.8	0.4659	12.7	**<.0001**
F x CV x Y	8	45	1.2	0.3019	1.5	0.1989	0.8	0.5801	3.0	**0.0083**
BL	3	42	0.2	0.8928	1.4	0.2434	0.2	0.8936	1.8	0.1709

			Tuber DM yield (t ha^{-1})		Tuber FM yield (t ha^{-1})		Tuber FM yield 40-65 mm (t ha^{-1})		Tuber yield >50mm (>35mm) (%)	
	Numerator d.f.	Denominator d.f.	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value
F	4	42	4.3	**0.0051**	9.5	**<.0001**	6.5	**0.0004**	3.2	**0.0216**
CV	1	45	16.5	**0.0002**	0.3	0.6011	2.9	**0.098**	49.0	**<.0001**
Y	2	42	30.2	**<.0001**	17.9	**<.0001**	24.5	**<.0001**	297.1	**<.0001**
F x CV	4	45	2.4	0.0663	0.8	0.5133	0.9	0.4607	0.4	0.8273
F x Y	8	42	2.0	0.0743	1.9	0.0883	0.9	0.5415	1.1	0.3611
CV x Y	2	45	9.8	**0.0003**	11.0	**0.0001**	9.0	**0.0005**	13.3	**<.0001**
F x CV x Y	8	45	1.0	0.4634	1.1	0.3931	0.9	0.5274	1.0	0.4345
BL	3	42	0.6	0.6123	0.8	0.4819	0.2	0.8898	0.1	0.9548

p-values in bold represent significant effects

2.3.3 Tuber N and K uptake and concentration

Highest N uptake and concentration was measured in 2003 (127 kg N ha^{-1}) when also very high tuber DM and N concentrations were recorded (Table 2.6a and b). Tuber N uptake and concentration were significantly influenced by fertilization and the year with consistently highest values for both parameters after application of either PSHG or HG. The two cultivars differed significantly in terms of tuber N uptake only in 2002 (Table 2.6a).

Tuber K uptake was significantly higher in 2003 (189 kg K ha^{-1}) as compared to 2002 (162 kg K ha^{-1}) and 2004 (165 kg K ha^{-1}). It was significantly affected by fertilizer application, cultivar and year, while the response to factor cultivar depended upon the year ($p<0.001$). Highest K uptake was measured after PSHG, which was significantly higher than after CM and PS alone, while the latter two treatments caused significantly higher K uptake than HG and CON (Table 2.6b). The K uptake of cv. Marlen was higher compared to cv. Agria in two of three seasons (2002 and 2003).

Tuber K concentration was affected by fertilizer application and the year significantly. Up to three-way interactions were established (F x CV x Y: $p< 0.01$). Nevertheless, there was a significant response, i.e. an increased tuber K concentration due to CM, PS and PSHG fertilization in every case - except for cv. Agria in 2003 (Table 2.6d).

Table 2.6: (a) Tuber N and (c) K uptake and (b) N and (d) K concentration as affected by fertilization and cultivar; means ± SD

(a) Tuber N uptake (kg N ha^{-1})

Year	2002		2003		2004		2002-2004
Cultivar	Agria	Marlen	Agria	Marlen	Agria	Marlen	
Fertilization	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
CM	64 ± 10.8 b	79 ± 15.5 b	122 ± 25.3 ns	112 ± 5.1 b	96 ± 8.9 c	98 ± 13.7 b	95 ± 23.8 c
PS	79 ± 9.8 ab	86 ± 7.7 b	117 ± 7.9	116 ± 13.0 b	91± 3.7 c	87 ± 2.3 b	96 ± 16.8 c
PSHG	93 ± 11.3 b	114 ± 18.4 a	130 ± 9.8	151 ± 13.0 a	134 ± 16.9 a	124 ± 9.0 a	124 ± 21.9 a***
HG	94 ± 9.5 a	109 ± 10.0 a	127 ± 11.3	138 ± 16.4 ab	109 ± 14.8 b	122± 7.0 a	116 ± 17.9 b***
CON	76 ± 8.4 b	86 ± 17.4 b	118 ± 15.4	110 ± 6.2 b	87 ± 8.1 c	88 ± 6.0 a	94 ± 18.3 c
Mean	81 ± 14.7 B	95 ± 19.2 A	123 ± 14.4	125 ± 19.5 NS	103 ± 20.2	104 ± 18.3 NS	
LSD (5%)				17.3			7.5

(b) Tuber N concentration (g kg^{-1})

Year	2002		2003		2004		2002-2004
Cultivar	Agria	Marlen	Agria	Marlen	Agria	Marlen	
Fertilization	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
CM	13.1 ± 1.51 b	13.1 ± 1.44 b	17.2 ± 1.77 b	16.5 ± 0.49 c	13.6 ± 0.66 b	14.9 ± 1.60 b	14.8 ± 2.05 b
PS	13.4 ± 0.90 b	13.2 ± 1.00 b	16.9 ± 0.43 b	17.3 ± 1.18 bc	13.8 ± 0.55 b	13.9 ± 0.82 b	14.8 ± 1.87 b
PSHG	16.8 ± 1.35 a	17.1 ± 1.01 a	19.3 ± 1.36 a	19.3 ± 0.44 a	17.4 ± 0.77 a	16.8 ± 0.86 a	17.8 ± 1.43 a***
HG	17.8 ± 1.82 a	16.6 ± 1.69 a	19.1 ± 1.07 a	18.5 ± 1.29 ab	16.9 ± 2.48 a	17.4 ± 0.45 a	17.7 ± 1.67 a***
CON	14.3 ± 1.91 b	13.2 ± 1.40 b	17.3 ± 0.83 b	16.7 ± 0.52 c	14.7 ± 0.74 b	14.0 ± 0.98 b	15.0 ± 1.80 b
Mean	15.1 ± 2.36	14.7 ± 2.20 NS	18.0 ± 1.48	17.7 ± 1.36 NS	16.3 ± 1.97	15.4 ± 1.74 NS	
LSD (5%)				1.75			0.83

Means of fertilizer treatments denoted by different lower letters are significantly different at $p < 0.05$; means of cutlivars denoted by different upper case letters are significantly different at $p < 0.05$; Asterisks show significant differences between a fertilizer treatment and CON at $p < 0.05$ (*); $p < 0.01$ (**) and $p < 0.001$ (***) ns = no significant effect of fertilizer treatment; NS = no significant effect of cultivar treatment.

Table 2.6 continued

(c) Tuber K uptake (kg K ha^{-1})

Year	2002		2003		2004		2002-2004
Cultivar	Agria	Marlen	Agria	Marlen	Agria	Marlen	
Fertilization	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
CM	139 ± 11.9 b	178 ± 20.0 ab	177 ± 19.9 ns	184 ± 10.9 b	188 ± 17.1 ab	169 ± 29.6 ab	172 ± 23.7 b*
PS	169 ± 16.3 a	181 ± 5.9 ab	180 ± 9.6	188 ± 12.9 ab	169 ± 17.4 bc	162 ± 17.4 b	175 ± 15.9 b*
PSHG	162 ± 10.1 a	192 ± 18.7 a	180 ± 16.7	215 ± 12.3 a	201 ± 31.8 a	193 ± 31.8 a	190 ± 24.8 a***
HG	139 ± 6.6 b	163 ± 11.6 b	170 ± 17.4	185 ± 14.3 b	149 ± 20.1 c	147 ± 20.1 b	159 ± 23.0 c
CON	138 ± 23.0 b	161 ± 11.5 b	179 ± 15.9	181 ± 23.0 b	131 ± 25.1 c	147 ± 25.1 b	156 ± 26.5 c
Mean	149 ± 18.9 B	175 ± 17.5 A	177 ± 15.2 B	191 ± 18.6 A	167 ± 28.4	163 ± 28.4 NS	
LSD (5%)				28.2			12.5

(d) Tuber K concentration (g kg^{-1})

Year	2002		2003		2004		2002-2004
Cultivar	Agria	Marlen	Agria	Marlen	Agria	Marlen	
Fertilization	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
CM	28.7 ± 0.59 a	29.8 ± 0.45 a	25.2 ± 0.46 ns	27.1 ± 0.73 a	26.7 ± 1.61 a	25.7 ± 1.41 a	27.2 ± 1.87 a***
PS	28.7 ± 0.15 a	27.9 ± 0.80 a	26.0 ± 0.32	28.2 ± 0.44 a	25.5 ± 1.86 a	25.8 ± 1.54 a	27.0 ± 1.61 a***
PSHG	29.2 ± 0.64 a	29.2 ± 0.50 a	26.7 ± 2.04	27.6 ± 0.64 a	26.1 ± 1.17 a	25.9 ± 1.37 a	27.4 ± 1.74 a***
HG	26.2 ± 0.41 b	24.8 ± 1.17 b	25.7 ± 1.63	25.0 ± 0.98 b	23.0 ± 3.29 b	21.0 ± 2.31 c	24.3 ± 2.45 b
CON	25.8 ± 1.10 b	25.0 ± 1.05 b	26.2 ± 0.52	27.2 ± 1.74 a	22.0 ± 1.80 b	23.2 ± 1.94 b	24.9 ± 2.24 b
Mean	27.7 ± 1.57	27.3 ± 2.26	26.0 ± 1.21	27.0 ± 1.43	24.6 ± 2.63	24.3 ± 2.52 NS	
LSD (5%)				1.88			1.01

Means of fertilizer treatments denoted by different lower letters are significantly different at $p < 0.05$; means of cutlivars denoted by different upper case letters are significantly different at $p < 0.05$; Asterisks show significant differences between a fertilizer treatment and CON at $p < 0.05$ (*); $p < 0.01$ (**) and $p < 0.001$ (***) ns = no significant effect of fertilizer treatment; NS = no significant effect of cultivar treatment.

2.3.4 Tuber DM, total and graded FM yield

Tuber DM yield, total FM and graded tuber yields (40-65 mm) and the portions of tubers >50 mm (in yield >35 mm) responded significantly to fertilization, cultivar and year. Significant interactions for CV x Y were established (Table 2.4). Moreover, the most profound impact on total and graded yield was exerted by the year, and by CV (tuber DM yield; % >50 mm (>35 mm)).

Tuber DM was highest after application of PSHG. CM also caused significantly higher tuber DM yields (+0.7 t ha^{-1} or +11.4%) than CON. Only in 2002, tuber DM yield of cv. Marlen was higher (+19%) compared with cv. Agria (Table 2.7a).

In contrast to tuber DM yield, tuber fresh matter (FM) yield was increased by every fertilizer. However, PSHG gave a stronger yield response (+6.1 t ha^{-1}) than CM, PS or HG, compared with the control. The latter treatments did not differ significantly from each other. While in 2002, cv. Marlen yielded significantly higher than cv. Agria, the opposite was true in 2004. In 2003, total FM yield (mean of both cultivars) was 31.3 t ha^{-1} (Table 2.7b).

The response of yield graded for later processing of tubers into crisps (40-65 mm) to individual fertilizers was analogous to that of total yields. In each of the three years, PSHG plots had significantly higher yields than unfertilized plots. CM increased tuber yield (40-65 mm) significantly in 2004 with cv. Agria. In 2002 and 2003 cultivar did not affect final graded tuber yield (crisps), and was significant only in 2004, when cv. Agria (+ 3.4 t ha^{-1}) had considerably higher yields than cv. Marlen (Table 2.7c).

In 2004, CM application increased tuber raw stock for processing into French fries (+ 5.6 t ha^{-1}). The portion of tuber FM yield >50 mm in tuber raw stock >35 mm was highest in 2004 (68%), followed by 2003 (49%) and 2002 (29%). On average of all years, only PSHG gave a significant increase in the portion of tuber yield >50 mm. The impact of the cultivar was particularly strong in 2003.

Table 2.7: (a) Tuber DM yield, (b) FM yield (t ha^{-1}), (c) 40-65 mm (t ha^{-1}) and (d) portion (%) of tuber yield >50 mm (of yield >35 mm) as affected by fertilization and cultivar in 2002 -2004; means ± SD

(a) Tuber DM yield (t ha^{-1})

Year	2002		2003		2004		2002-2004
Cultivar	Agria	Marlen	Agria	Marlen	Agria	Marlen	
Fertilization	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
CM	4.8 ± 0.38 b	6.0 ± 0.67 ns	7.0 ± 0.77 ns	6.8 ± 0.26 b	7.0 ± 0.63 ab	6.6 ± 1.20 ab	6.4 ± 1.02 b
PS	5.9 ± 0.56 b	6.5 ± 0.14	6.9 ± 0.29	6.7 ± 0.54 b	6.6 ± 0.38 bc	6.3 ± 0.39 b	6.5 ± 0.49 b
PSHG	5.5 ± 0.34 a	6.6 ± 0.69	6.8 ± 0.63	7.8 ± 0.63 a	7.7 ± 0.71 a	7.4 ± 0.89 a	7.0 ± 0.99 a**
HG	5.3 ± 0.29 b	6.6 ± 0.50	6.6 ± 0.45	7.4 ± 0.78 ab	6.4 ± 0.50 bc	7.0 ± 0.28 ab	6.6 ± 0.80 b
CON	5.3 ± 0.73 b	6.5 ± 0.70	6.8 ± 0.66	6.6 ± 0.49 b	5.9 ± 0.50 c	6.3 ± 0.71 b	6.3 ± 0.76 b
Mean	5.4 ± 0.56 B	6.4 ± 0.57 A	6.8 ± 0.54 NS	7.1 ± 0.70	6.7 ± 0.78 NS	6.7 ± 0.82	
LSD (5%)			0.85				0.37

(b) Tuber FM yield (t ha^{-1})

Year	2002		2003		2004		2002-2004
Cultivar	Agria	Marlen	Agria	Marlen	Agria	Marlen	
Fertilization	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
CM	25.4 ± 3.09 b	29.0 ± 3.65 ab	31.3 ± 2.57 ns	29.7 ± 1.16 b	37.2 ± 3.54 ab	33.0 ± 4.50 ab	31.0 ± 4.70 b
PS	29.7 ± 2.89 ab	30.5 ± 0.83 a	32.0 ± 2.33	30.8 ± 3.03 ab	34.0 ± 2.88 b	29.7 ± 2.61 b	31.1 ± 2.72 b
PSHG	30.0 ± 2.00 a	33.0 ± 3.69 a	32.1 ± 2.03	35.0 ± 2.82 a	41.9 ± 4.99 a	37.1 ± 5.37 a	34.8 ± 5.15 a***
HG	28.4 ± 1.65 ab	31.1 ± 1.66 ab	30.7 ± 2.02	32.1 ± 3.66 ab	34.0 ± 3.50 b	32.6 ± 1.85 bc	31.5 ± 2.88 b*
CON	26.2 ± 3.72 ab	28.4 ± 2.80 b	30.7 ± 2.87	28.4 ± 1.97 b	29.5 ± 2.89 c	29.1 ± 3.81 b	28.7 ± 3.05 c
Mean	27.9 ± 3.09 B	30.4 ± 2.95 A	31.4 ± 2.22 NS	31.2 ± 3.33	35.3 ± 5.32 A	32.3±4.48 B	
LSD (5%)			4.32				2.03

Table 2.7 continued

(c) Tuber FM yield (40-65 mm) (t ha^{-1})

Year	2002		2003		2004		2002-2004
Cultivar	Agria	Marlen	Agria	Marlen	Agria	Marlen	
Fertilization	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
CM	19.6 ± 4.03 b	23.7 ± 5.06 ab	25.7 ± 2.17 ns	24.0 ± 1.72 b	31.8 ± 2.12 ab	27.6 ± 2.79 ab	25.4 ± 4.77 b
PS	24.1 ± 2.81 a	23.9 ± 1.47 ab	26.6 ± 2.35	24.8 ± 2.90 ab	29.9 ± 2.01 abc	24.5 ± 2.72 b	25.6 ± 3.04 b
PSHG	24.8 ± 2.86 a	26.9 ± 4.50 a	26.7 ± 1.76	28.4 ± 1.73 a	34.0 ± 5.80 a	30.3 ± 5.36 a	28.5 ± 4.67 a***
HG	21.3 ± 3.64 ab	23.2 ± 1.48 ab	25.2 ± 1.86	26.0 ± 3.55 ab	28.4 ± 1.30 bc	26.2 ± 1.48 ab	25.0 ± 3.16 b
CON	21.1 ± 3.18 ab	21.9 ± 1.31 b	25.9 ± 2.85	22.5 ± 1.64 b	25.9 ± 2.24 c	24.8 ± 3.67 b	23.7 ± 3.04 b
Mean	22.2 ± 3.57	23.9 ± 3.32 NS	26.0 ± 2.07	25.1 ± 2.97 NS	30.0 ± 4.00 A	26.6 ± 3.69 B	
LSD (5%)				4.30			1.96

(d) Tuber FM yield >50 mm of >35 mm) (%)

Year	2002		2003		2004		2002-2004
Cultivar	Agria	Marlen	Agria	Marlen	Agria	Marlen	
Fertilization	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
CM	32.8 ± 9.45 ns	32.0 ± 6.22 ns	49.2 ±16.52 b	40.4 ± 13.82 ab	72.9 ± 9.16 ns	61.5 ± 4.55 ns	48.1 ± 18.07 b
PS	30.6 ± 5.83	24.1 ± 6.07	61.6 ± 3.79 a	40.4 ± 17.03 ab	69.8 ± 5.99	65.2 ± 4.38	48.6 ± 19.59 b
PSHG	33.5 ± 4.32	28.4 ± 9.55	63.8 ± 6.46 a	41.5 ± 7.02 a	75.8 ± 2.22	71.7 ± 2.24	52.5 ± 19.84 a**
HG	30.9 ± 5.40	23.0 ± 5.96	63.1 ± 4.82 a	39.8 ± 6.65 ab	71.7 ± 6.69	67.4 ± 5.72	49.3 ± 20.00 b
CON	27.9 ± 5.59	25.5 ± 8.64	60.8 ± 7.69 a	29.7 ± 4.58 b	65.0 ± 0.94	61.5 ± 3.93	45.1 ± 18.55 b
Mean	31.1 ± 5.99	26.6 ± 7.41 NS	59.7 ± 9.75A	38.3 ± 10.67 B	71.1 ± 6.37	65.5 ± 5.51 NS	
LSD (5%)				10.88			4.21

Means of fertilizer treatments denoted by different lower letters are significantly different at $p < 0.05$; means of cutlivars denoted by different upper case letters are significantly different at $p < 0.05$; Asterisks show significant differences between a fertilizer treatment and CON at $p < 0.05$ (*); $p < 0.01$ (**) and $p < 0.001$ (***) ns = no significant effect of fertilizer treatment; NS = no significant effect of cultivar treatment.

2.4 Discussion

Farmyard manure (FYM) in stocked organic farming systems plays a very important role for crop nutrition and the maintenance of soil fertility (Mäder et al., 2002). The considerable variation of N, P and K content, DM concentration and C to N ratios shows that variability in chemical composition of CM from organically-managed farms can be expected to be just as wide as in the case of conventional farming. Previous studies showed that content of the most important nutrients in CM from organic farms were found to be in the lower to mid-range when compared to the conventional reference (Piorr et al., 1991). The average N and K contents of the material used in the experiments (means of 2002-2004) were higher than those found in the survey of Dewes and Hünsche (1998) for CM from organic holdings, but were within the same range for P. In 2002, a high proportion of straw from bedding material resulted in the relatively high C to N ratio of 37, compared to the two other experimental years when the ratios were more consistent with those found in a recent study on organic holdings in England (Shepherd et al., 2002).

2.4.1 Mineralized N and available K

Prior to emergence of the potato crop, the mother tuber supplies the growing plant with nutrients (Harris, 1992). Hence, the mineralized nitrogen in soil at crop emergence provides valuable information on the initial status of available nitrogen. At BBCH 09 supplemental N added by CM had obviously not been mineralized yet. At that time, the level of NO_3-N at 0-60 cm ranged from 95 in 2002 to 161 kg N ha^{-1} in 2003 (Figure 2.1a-c). Möller (2001) classified three groups of N supply (low–medium–high) in organic potato cropping. Our results represent a medium (2002 and 2004) and a high N supply (2003) according to this classification. The very high level in 2003 confirms that a higher supply of NO_3-N can be expected after grass/clover when compared to cereals (Stein-Bachinger and Werner, 1997; Neuhoff and Köpke, 2002). The impact of the preceding crop was much more important than the effect of fertilization. At crop emergence, the effect of fertilizer application on NO_3-N at 0-30 cm was significant. However, in plots fertilized with CM, topsoil content was not significantly different from those in unfertilized plots. Both Neuhoff (2000) and Stein-Bachinger (1993) measured a minor, yet significant increase in mineralized N (NO_3-N and NH_4-N) at emergence of only 20 kg ha^{-1} after application of 240 kg N ha^{-1} with CM in spring. Results suggest that organically bound N from horn-based fertilizers is much more readily available than from CM.

After a spring peak at crop emergence, soil content of NO_3-N gradually declined and did not increase before harvest of the crop which was in accordance with other studies on organic potato cultivation (Stein-Bachinger, 1993; Heß, 1995; Möller et al., 1999).

A soil K content of 40-100 g kg^{-1} in topsoil is commonly considered to be sufficient for tuber yields expected under conditions of limited N supply (Meinck and Kolbe, 1999). According to the (conventional) soil nutrient status classification, the individual soil K index of the fields varied between low (2002 and 2004) and medium (2003) (Heyn and Schaaf 2002). No significant differences between CM and mineral K supply were established in years when fertilization had an impact on K availability (Table 2.3). This indicates that a very high proportion of K from CM is readily available in the first year, which was also observed by Böhm and Dewes (1997) and Neuhoff (2000).

2.4.2 N and K concentration in canopy DM at BBCH 69

A wide range of N concentrations of the canopy dry matter was found in the years 2002 and 2003. There was no positive correlation with the N status at planting. Yet, it could be shown that the nutritional status of aboveground biomass can be improved by application of horn grits, while response to cattle manure may hardly be predicted, keeping in mind that data on 2004 were missing. Furthermore, results do not clearly indicate by which fertilizer (cattle manure or mineral K) the K status of the canopy can most likely be augmented.

2.4.3 Tuber N and K uptake and concentration

Neuhoff and Köpke (2002) found a higher relative N uptake in response to increasing rates of CM on sandy Luvisol compared to a fertile Fluvisol. Böhm and Dewes (1997) observed an increasing N recovery by tubers when increasing rates of cattle manure (0-15-30 t ha^{-1}) were applied on soils comparable to those from the present study. Response of N uptake was consistently affected only by application of horn grits. The higher N uptake in 2003 compared with 2004 can be explained by both higher tuber DM yield (Table 2.7a) and the higher tuber N concentrations (Table 2.6b) in that year. Crop growth in 2003 proceeded undisturbed by late blight, while the leaves in mid July 2004 were already severly damaged, the disease

subsequently advancing very slowly. The significantly higher N uptake by tubers of cv. Marlen in 2002 and 2003 was probably due to the higher tuber DM yield of this cultivar, since tuber N concentration was not affected by cultivar (Table 2.6b).
Increased recovery of K by tubers after application of mineral potassium fertilizer was also observed by Allison et al. (2001) who found the increase in K taken up to be primarily due to increased tuber DM yield. Accordingly, we found the higher K uptake after PS application to be due to tuber DM yield instead of a higher K concentration (Table 2.6c). Tuber K uptake was significantly increased by CM only in 2004, the year when a significant yield response to cattle manure could be established. Comparing CM and PS, the results of the three growing seasons give evidence of the higher tuber uptake of K when applied as mineral fertilizer.

2.4.4 Tuber DM, total and graded FM yield

The higher tuber DM yield in 2003 compared with 2004 can be explained by the higher DM concentration that compensated for the lower tuber fresh matter yield in that year as crop growth proceeded without late blight epidemics (Table 2.7a and b). Higher tuber DM yield after grass/clover when compared with cereals was also found by Möller (2001). The lower tuber DM yield in 2002 as compared with 2004 can be traced back to both lower FM and a lower tuber DM concentration in 2002 (Haase et al., 2007). In 2002, late blight resulted in premature senescence of the crop in late July, while 2004 was characterized by a moderate development of the disease.
Fertilization affected tuber DM yield in 2004, analogously to total tuber fresh matter. When increasing rates of composted organic manures were tested in previous studies, yield response of organic potatoes was often insignificant and explained by either the high N status of the soil (Stein-Bachinger and Werner, 1997), an early late blight attack (Matthies, 1991), or poor mineralisation of N from manure (Neuhoff and Köpke, 2002). However, on sandy soils, increasing rates of CM were shown to cause significantly higher yields (Böhm and Dewes, 1997). In our experiments on loamy sand, we found a clear response of tuber fresh matter yield on fertilizer application. FYM application rates of up to 40 t ha^{-1} as used in the present study are well within the range applied in organic potato production (Rahmann et al., 2004). However, seasonal influences such as pre-cropping and weather conditions obviously make response of tuber yield to cattle manure application unpredictable

for the farmer. Only in 2004 did application of both, CM and PSHG prove to be efficient in terms of a response of yield and K uptake. This may possibly be traced back to the high availability of K from CM and a more balanced nutrition with regard to N and K, respectively (Herlihy and Carroll, 1969). This suggestion is further strengthened by the profound effect of PSHG on FM tuber yield compared with sole application of N (HG) and K (PS). Results indicate that the increase in total tuber FM yield after CM in 2004 was most probably due to K.

Tubers graded 40-65 mm may be regarded to be optimal for crisps production (Schuhmann, 1999). Graded tuber yield reflected the response of total tuber FM yield on fertilizers, and was significantly affected in every single growing season. The results show that in years without late blight, as in 2003, or with early, yet moderate late blight epidemics such as 2004, soil amendments with fertilizers acceptable in organic farming may increase marketable yields for the crisps industry and thereby financial returns for the organic farmer. Sole HG or PS application does not seem to provide a nutritive regime favourable for increased tuber yield >40 mm. Herlihy and Carroll (1969) stated that the efficiency of increasing N supply to the potato crop is higher with increasing rates of K.

Application of composted CM was found to increase the number of tubers >65 mm (Stein-Bachinger and Werner, 1997) on a fertile Luvisol and reduce the absolute and relative yields of smaller tubers as a result of N mineralization (Stein-Bachinger and Werner, 1997; Neuhoff, 2000). In organic potato cropping, large proportions of non-marketable oversized tubers are rarely reported, due to the limited N supply (Karalus and Rauber, 1997). Results confirm, that on a loamy sand which is commonly used for potato cultivation, fertilization with N and K most probably does not cause increases of yield of oversized tubers. Overall, the response of graded tuber yield (40-65 mm) to CM was insignificant, which may be explained by poor or late mineralization of N.

The *organic* French fry industry currently demands raw stock (>35 mm) with a proportion of at least 50% of tubers >50 mm. In 2004, the threshold was exceeded regardless of treatment, while in 2003 raw stock would have been marketable only after application of PSHG, or sole application of its components. The higher portion of 68% (2004) when compared with 49% (2003) cannot be explained by a higher supply of mineralized N in topsoil at crop emergence (Fig. 2.1). In 2004, even the unfertilized plots (means of both cultivars) yielded higher portions of large tubers than the PSHG treatment in 2003. This does not, however, account for cv. Agria.

The results indicate that, in organic potato cropping for processing into French fries, the choice of cultivar may be more important than fertilization when only the larger tubers are marketable. Moreover, the influence of the year may make response of marketable yield rather difficult to predict for the farmer.

2.5 Conclusion

An increase in soil N status at early crop growth stages can best be accomplished by applying horn grits, rather than cattle manure, or by cultivating potatoes after a pre-crop such as grass-clover, as compared to cereal grains. Results show clearly that the use of cattle manure in organic agriculture impedes the optimization of more than one nutrient in terms of the nutrition of the potato crop. This suggestion was supported by the fact that response of tuber N uptake and concentration to cattle manure was found to be insignificant, indicating a low potential of fresh cattle manure to increase plant available N. Accordingly, a yield response to cattle manure cannot be predicted and data on tuber K uptake imply the yield response to CM to be due to an increased availability of K rather than NO_3-N. Moreover, it can be concluded that K availability can be increased by cattle manure and mineral K fertilization equally. The high level of tuber K contents even from unfertilized plots suggests that loamy sand may have a potential to supply K from its reserves, not accounted for in the soil analysis commonly used.

In order to increase tuber FM yields, the combination of mineral K fertilizer and an organic N source, such as horn grits proved to be an excellent alternative to CM in terms of NO_3-N content of top soil, tuber N uptake and concentration. Apart from tuber yield, however, the portions of certain size-grades and the dry matter concentration play an important role. In this connection, the choice of cultivar may be a more important agronomic measure to increase financial returns than fertilization.

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3 The effect of preceding crop and pre-sprouting on crop growth, N use and tuber yield of maincrop potatoes for processing under conditions of N stress

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Abstract

Factorial field trials were carried out on an experimental farm near Kassel, Germany, in two consecutive seasons (2003 and 2004) in order to examine the impact of leguminous and cereal preceding crops (i) on soil N availability under subsequent potatoes and (ii) the effect of preceding crop and pre-sprouting of seed tubers on crop development, N uptake, N utilization efficiency and total and size-graded tuber yields relevant for processing into either crisps or French fries. In addition, an approach to analyze complex field experiments using mixed models is discussed.

Soil mineralized nitrate-N at emergence of the potato crop was affected by the preceding crop and was highest when potatoes followed peas, while the short-term alfalfa/grass/clover ley appeared too sensitive to environmental conditions in the preceding cropping season, and its efficiency in terms of N supply may be hard to predict. Pre-sprouting advanced crop development and dry matter accumulation of the canopy, translocation of assimilates and N from canopy into tubers and allowed an increased N utilization efficiency. The positive effect of pre-sprouting on total tuber yield was compensated up to final harvest in 2003, but a higher percentage of marketable tuber yields for French fries (> 50 mm) was found independently of the date of harvest. An increasing N supply (after peas and a following catch crop) may be efficient in terms of higher yields of the marketable size-grades (40–65 mm) for crisps, but increase oversized tuber yields in seasons not affected by *Phytophthora infestans*. Average tuber fresh weight responded consistently and positively to seed-tuber preparation (pre-sprouting), cultivar (cv. Agria) and an increased N supply (after peas).

Key words: mixed models – nitrogen stress – organic farming – preceding crop – pre-sprouting – *Solanum tuberosu*m L.

3.1 Introduction

Nitrogen (N) supply and the occurrence of late blight, caused by *Phytophthora infestans*, are the two factors generally stated to be most limiting to tuber yield in organic potato (*Solanum tuberosum* L.) cropping (Karalus and Rauber 1996; Van Delden 2001). The principles of organic farming require that fertilizers be used for soil fertilization and conditioning only to the extent that adequate nutrition of the crop is not possible through the recycling of organic materials alone (IFOAM 2002). Hence, crop rotation plays a crucial role in organic crop nutrition. There is little information on the impact of preceding crops on crop development and potato tuber yield in organic farming systems (Finckh et al. 2006). Yield response is mainly dependent on the rate at which N is released from preceding crops (Köpke 1995), but N mineralization from organic residues may be difficult to synchronize with crop demand (Pang and Letey 2000). As a consequence it was implied, that organically cultivated potato crops may be at risk of suffering from N stress and that this may have detrimental effect upon tuber yield formation.

Organic farmers rely on preventive rather than curative measures of plant protection against late blight. Pre-sprouting can limit yield losses caused by late blight (Karalus and Rauber 1997), because it advances early crop development. Pre-sprouting promotes apical dominance (Hay and Walker 1989), thereby decreasing the number of tubers per plant and lowering competition between individual tubers for limited N and water. It is assumed that this may influence marketable yield of tuber raw material graded for processing into either French fries (> 50 mm) or crisps (40-65 mm). It was suggested that the rate at which N is supplied to the crop at early growth stages interacts with seed-tuber preparation. So far, there is no published data on the effect of pre-sprouting at varying levels of nitrogen supply called forth by different crops preceding potatoes in crop rotation.

This study was conducted to quantify the effects of the preceding crop and seed tuber preparation on soil N availability, potato crop development, N uptake and N utilization efficiency, as well as total and graded tuber yield for industrial processing, under conditions of organic farming.

3.2 Material and Methods

3.2.1 Site description

The study was conducted at the Hessische Staatsdomäne Frankenhausen, the research farm of the University of Kassel (51.4 N; 9.4 E), Germany, located 230 m above sea level. The farm was converted to organic farming (OF) between 1999 and 2001 and is a certified member of two OF associations (Naturland and Bioland). Soil type of both experimental fields was a Haplic Luvisol, soil texture a silt loam (Brandt et al. 2001).

In 2003, precipitation was extraordinarily low from March through September, except in June, when rainfall exceeded the long-term average by 20 mm. In contrast, rainfall in 2004 was in accordance with the long-term mean. However, exceptionally high precipitation was measured in July (135 mm), compared to the mean of 30 years (1960-1990) for July (65 mm). A pronounced deviation from the long-term average daily temperature was measured from June through August in 2003, while in May 2004 it was very low (Table 3.1).

Table 3.1: Rainfall and average daily temperature at the experimental site during 2003–2004

			Departure from long-term mean			
	Long-term mean (1960-1990)		2003		2004	
	Rainfall in mm month^{-1}	Average daily temperature (℃)	mm month^{-1}	℃	mm month^{-1}	℃
Jan	55	0.2	14	0.0	44	0.4
Feb	43	1.2	-27	-2.7	19	1.7
Mar	51	4.4	-20	1.8	-13	0.1
Apr	50	8.3	-27	0.6	-3	1.4
May	67	12.9	-30	1.2	-23	-1.4
Jun	79	16.0	19	3.2	-23	-0.7
Jul	64	17.5	-13	1.6	71	-1.1
Aug	63	17.2	-49	4.0	-18	1.4
Sep	54	13.9	-8	-0.1	1	0.1
Oct	46	9.6	-10	-3.4	0	0.8
Nov	59	4.5	-30	2.0	32	-0.4
Dec	67	1.4	-5	0.3	-34	-1.3

[1] Deutscher Wetterdienst 2005

3.2.2 Design and Husbandry

Experiments were conducted in two consecutive seasons (2003 and 2004), but on different fields. On both fields, the pre-preceding crop was spring barley (*Hordeum vulgare* L. cv. Theresa). In the pre-test seasons (2001-2002 and 2002-2003), prior to planting of potatoes, four different crops were cultivated in strips of 76 m x 6 m: winter wheat (*Tritcum aestivum* L. cv. Bussard; WW), oats (*Avena sativa* L. cv. Jumbo; OAT), peas (*Pisum sativum* L. cv. Classic; PEA) and an alfalfa-grass / clover ley (23% *Medicago sativa*, 11% *Trifolium pratense* L., 16 % *T. repens* L., 30% *Lolium perenne* L. and 20% *Festuca pratensis*; AGC). The AGC leys were cut and removed twice. Harvest of cereals and peas was immediately followed by soil tillage and a catch crop (CC) mixture of *Raphanus sativus* L. (cv. Siletta nova) and *Phacelia tanacetifolia* BENTH (cv. Vetrovska) sown at a ratio of 24 : 6 kg/ha. Both CC and AGC were ploughed under at frosty weather on 31 January 2003 and 28 January 2004. Details of the agronomical measures in the pre-test season and in the field experiments are given in Table 3.2.

Table 3.2: Management of field trials in the pre-test season and the two experimental years

	2001-2003	2002-2004
Previous crops (PC):		
WW sown	30 October 2001	15 October 2002
OAT & PEA sown	9 April 2002	25 March 2003
AGC sown	9 April 2002	15 April 2003
AGC first cutting	27 June 2002	10 July 2003
AGC second cutting	14 August 2002	3 September 2003
AGC first cutting DM in t ha^{-1}	3.2 (3.05-3.33)	3.3 (3.09-3.44)
AGC second cutting DM in t ha^{-1}	4.3 (4.19-4.47)	2.4 (2.15-2.53)
PEA DM yield	2.1 (1.83-2.28)	1.8 (1.62-2.04)
OAT DM yield	5.6 (5.10-6.24)	4.3 (4.12-4.56)
WW DM yield	5.3 (4.70-5.69)	5.6 (5.49-5.81)
Catch crop (CC)		
Sown	22 August 2002	18 August 2003
Sampling	29 November 2002	7 November 2003
Total N uptake of catch crop after [kg N ha^{-1} (range)]		
PEA	120 (114.7-124.3)	89 (70.8-117.9)
OAT	37 (32.5-46.2)	29 (25.1-31.5)
WW	29 (24.1-34.4)	36 (29.8-39.9)
Tillage and weed control		
Cultivator OAT; PEA; WW	21 August 2002	17 August 2003
Ploughing under AGC+CC	31 January 2003	28 January 2004
Rotary cultivator	23 April 2003	21 April 2004
First/second hilling	4/16 June 2003	1/14 June 2004
Manual weeding	6 June 2003	3 June 2004

Table 3.2 continued

Soil sampling (nitrate-N)		
Under CC and AGC	29 November 2002	5 November 2003
Spring	11 April 2003	17 April 2004
Emergence [1]	15 May 2003	18 May 2004
First harvest	15 July 2003	29 July 2004
Second harvest	29 July 2003	17 August 2004
Final harvest	17 September 2003	18 September 2004
Potato crop		
Presprouting (start)	14 March 2003	15 March 2004
Planting	24 April 2003	22 April 2004
First harvest (DAP)	83	95
Canopy	14 July 2003	27 July 2004
Tuber	16 July 2003	29 July 2004
Second harvest (DAP)	95	114
Canopy	27 July 2003	not conducted
Tubers	28 July 2003	17 August 2004
Final harvest		
Tubers	18 September 2003	17 September 2004
Soil nutrient status at crop emergence		
P (CAL) [mg kg^{-1} (range)]	69 (64-72)	58 (57-59)
K (CAL) [mg kg^{-1} (range)]	98 (89-102) 1)	77 (74-82)
Mg ($CaCl_2$) [mg kg^{-1} (range)]	78 (77-83)	69 (68-70)
pH ($CaCl_2$)	6.6 (6.5-6.7)	6.8 (6.7-6.9)

Values in brackets indicate range. DAP, days after planting at tuber harvest.

[1] Precrops significantly affected K_{CAL} in 2003 (see Results)

A factorial treatment combination was arranged in a split-plot design with preceding crop as mainplot (PC), date of harvest as subplot (early or final; HAR), cultivar as sub-subplot (Agria or Marlen; CV) and pre-sprouting as sub-sub-subplot (yes or no; PS). The experiment had four replicates (REP). Main plots were laid out according to a randomized complete block design (Fig. 3.1).

Main plots (76 m x 6 m) were divided into two equal halves (38 m x 6 m), each half split into four adjacent equally-sized subplots (9.5 m x 6 m) and factor HAR randomly allocated to them. In order to permit two subsequent early mechanical harvests, the subplots for early harvests were additionally split into two equal parts of 9.5 m x 3 m to accommodate two harvests (TIME). In the two experimental seasons, randomization varied slightly: In 2003, the four subplot factor combinations of CV x PS were assigned in two single randomization steps for final and early harvests, respectively. In 2004, first CV was randomly assigned to subplots of 19 m x 6 m and, subsequently, as a sub-subplot factor, PS assigned to those sub-plots.

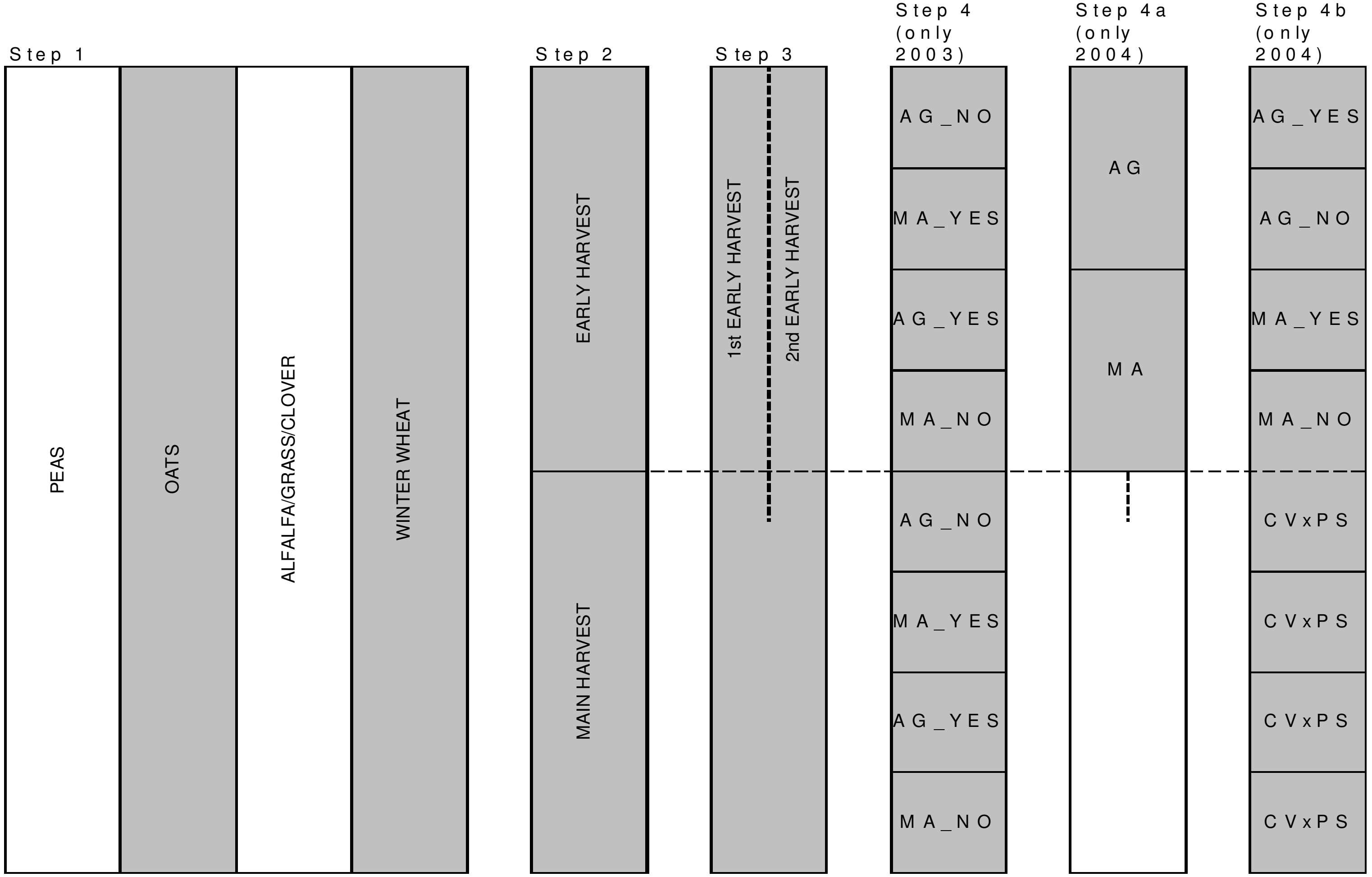

Figure 3.1: Randomization of the experiments in 2003 and 2004; AG-YES = pre-sprouted cv. Agria; AG-NO = not pre-sprouted cv. Agria (accordingly for MA = cv. Marlen)

All seed tubers were graded 40-50 mm, and tubers for treatment PS-YES were pre-sprouted, respectively, keeping two to three tuber layers in boxes (600 x 400 x 190 mm; Bekuplast, Ringe, Germany) illuminated at 20 °C for three days and 10-15 °C for the following 5-6 weeks. In contrast, seed for treatment PS-NO (not pre-sprouted) was stored in a dark, cool place (8-10 °C; 85 % RH), but only until three days before planting, to ensure acclimatisation.

Seed tubers were planted with a two-row planter at 34 cm with rows 75 cm apart, at a depth of 8-10 cm. Weeds were controlled by harrowing, hilling and manual weeding. Colorado beetle (*Leptinotarsa decemlineata*) was controlled using Novodor FC® (Agrinova, Neudorf, Germany) in 2003 and Neem Azal®-T/S (Trifolio-M GmbH, Lahnau, Germany) in 2004 according to application guidelines. Late blight was assessed weekly as percent diseased leaf area following the scheme given by James (1971). Aboveground crop development was recorded according to the BBCH (**B**iologische **B**undesanstalt und **CH**emische Industrie) growth stages for potatoes given by Hack et al. (1993).

3.2.3 Plant and soil sampling

Soil samples were taken in winter under the catch crop, in spring and then at emergence (BBCH 09), at first and second early harvest and at maturity (BBCH 99). Total biomass of the potato canopy was assessed from 32 plants at the two early harvests. Much of the canopy was lost by the late blight epidemic occurring within the sampling period 2004 and by decomposition after drought-induced senescence during July and August in 2003. Hence, samples of the canopy (stems and leaves) were only taken at first harvest (2003 and 2004) and at the second harvest (2003), whereas tubers were sampled in both years at all three corresponding harvests. Due to the very wet weather conditions in July 2004, both early harvests were carried out almost two weeks later than the year before. The potato crop was lifted with a one-row harvester and picked up by hand. Tubers from the inner four rows at BBCH 99 (64 plants) and two rows at each early harvest (32 plants) were sampled, weighed and counted to calculate total and graded yields, > 35 and > 50 mm for French fries and < 40, 40-65 and > 65 mm for crisps.

3.2.4 Laboratory analysis

Dry matter (DM) of the canopy from early harvests was determined from a subsample of around 500 g from any sub-plot by weighing before and after drying at 60 °C for 36 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 and stay dry. Subsequently, HCl (32 %) was added and the solution left overnight. After transfer into a retort made 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-analyzer (Elementar Analysesysteme, Hanau, Germany).

At each harvest, a subsample of 20 tubers (size-graded > 40 mm) per sub- (sub-) plot was cut into cubes of 1 cm^3 with a Dito TRS vegetable cutter (Dito Electrolux Co., Herborn, Germany) and the DM content determined by weighing before and after drying at 70 °C for 2.5 days. Immediately after drying, the samples were ground (0.5 mm) and stored in a dry, cool and dark place until further analysis. Tuber DM yield was determined from the tuber fresh weight (t/ha) multiplied by tuber DM (%) concentration divided by one hundred. N uptake of tubers or canopy was calculated by multiplying N (%) concentration by tuber DM yield and biomass of the canopy, respectively.

N utilization efficiency denotes the final fresh matter tuber yield (t FM/ha) per kg N taken up by the whole crop until the end of July (second early harvest in 2003, first early harvest in 2004) (Huggins and Pan 1993).

Mineralized nitrate-nitrogen (NO_3-N) in the soil profiles of 0-30, 30-60 and 60-90 cm was determined 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 hectare using bulk densities of 1.43, 1.50 and 1.60 g cm^{-3} for the 0-30, 30-60 and 60-90 cm horizons, respectively. Soil bulk densities were taken from a soil survey done by Brandt et al. (2001).

Available phosphorus (P), potassium (K) and magnesium (Mg) were determined at 0-30 and 30-60 cm according to the methods provided by Schüller (1969) and Hoffmann (1991). P was measured with a UV-1602 spectro-photometer (Shimadzu Co., Kyoto, Japan) at 580 nm against water and K with an ATI Unicam 939 atomic absorption spectrometer (ATI Unicam Ltd., Cambridge, UK). Mg was extracted with

0.0125 M calcium chloride ($CaCl_2$), the solution shaken for 2 h, 0.1 ml Schinkel solution added and Mg measured by atomic absorption spectrometry. Soil pH was determined from a solution of 20 g soil (+50 ml of 0.01 M $CaCl_2$) - after shaking for 0.5 h and leaving the solution overnight - with a Titran Line alpha TM pH-meter (Schott Instruments, Mainz, Germany).

3.2.5 Statistical analysis

Our design is not a standard one, so the linear model appropriate for analysis cannot be found in textbooks. Thus, we followed the general rules outlined in Piepho et al. (2003). These prescibe to independently develop a block model, representing the randomization structure, and a treatment model.

Analysis of variance, estimation of least square means and standard errors were performed using the MIXED procedure of the software package SAS 9.1.3 (SAS Institute 2004). Denominator degrees of freedom were approximated by the Kenward-Roger method. Due to experimental design, denominator degrees of freedom may vary between traits. Residuals were checked for normal (Gaussian) distribution and homogeneity of variance with PROC UNIVARIATE and PROC GPLOT. In the case of nitrate-N dynamics, data were log-transformed and subjected to analysis of variance. Least square means and their associated 95 % confidence limits were transformed back to the original scale, thus yielding estimates of medians. The dependent variables total and graded tuber yields were analyzed by fitting a mixed model using the following factors:

REP = complete replicate (block)
PC = preceding crop
CV = cultivar
PS = pre-sprouting
HAR = early or final harvest
TIME = first or second early harvest

TIME was nested within HAR, while the HAR/TIME structure was crossed with the other factors (PC, CV and PS). Thus, the full treatment model was (HAR/TIME)×PC×CV×PS. Replications were treated as fixed effects. According to randomization structure the design effects REP•PC, REP•PC•HAR, REP•PC•HAR•TIME, REP•PC•HAR•CV (only 2004), REP•PC•HAR•CV•TIME (only 2004) and REP•PC•HAR•CV•PS were considered as random effects and REP•PC•HAR•CV•PS•TIME as residual random error (Piepho et al. 2003).

N-uptake of canopy and tubers until the end of July (second harvest in 2003 and first harvest in 2004) were assessed only on plots corresponding to a single HAR•TIME combination. Thus, the mixed model described above was reduced by dropping all terms involving HAR or TIME. The reduced model was expanded to accommodate the factor year (YR), and effects REP•PC•YR, REP•PC and PC•YR were considered as random.

Soil samples were taken on a main-plot basis (mixed samples taken from all four factor combinations of CV•PS). The plots taken into account for soil sampling were the plots for final harvest, since only in these plots could soil be sampled until September (final harvest). The response of available P, K, Mg and pH in topsoil (0-30 cm) at crop emergence was therefore tested using a mixed model with fixed effects REP and PC and random residual effect REP•PC. The dynamics of soil nitrate-N in the soil profiles of 0-30 and 30-60 cm in the two experimental years (YR) were assessed from samplings under catch crop in November until just before final harvest of the potato crop (dates of sampling: under catch crop, spring, emergence, first and second early and final harvest). Depth of sampling (DS) and date (DT) were modelled as doubly repeated measures (Piepho et al. 2004). The treatment structure was PC×DS×DT×YR. The block effect was YR•REP•DS•DT. The variance-covariance matrix for residual error on a plot (YR•REP•DS•DT) was initially modelled as a direct (Kronecker) product structure corresponding to the repeated factors DS and DT. Throughout, an unstructured model was used for DS and various models were tried for DT, i.e., unstructured, AR(1), compound symmetry and identity. Comparing the log-likelihoods, we determined the identity model to provide the best fit, implying that serial correlation was absent among different dates, while spatial correlation among different depths of sampling was important.

Regression of the total crop (canopy + tubers) DM against tuber DM and FM yield assessed at the end of July was conducted using PROC REG.

3.3 Results

In 2003, only minor leaf infections of late blight (*P. infestans*) were observed around mid July accounting to a disease severity of just 0.001 %. Due to subsequent warm and unusually dry weather conditions (Table 3.1) no further spread or growth of the fungus was recorded. In 2004, late blight epidemics also started around mid July, but progressed steadily. At the end of July, the canopy was moderately infested (25-30 %). Two weeks later, around 50 % of the canopy was infected and at the 25th of August it was severely damaged by the fungus (75 % diseased leaf area). The two cultivars did not differ in terms of disease development (data not shown).

No statistically significant response of available P, K or Mg to preceding cropping was found, except for K in 2003, when at emergence of the subsequent potato crop the alfalfa/grass/clover ley (AGC) caused a significantly ($P < 0.05$) lower K content in topsoil (0-30 cm). In November highest nitrate-N (NO_3-N) in the 0-30 and the 30-60 cm soil profiles was measured after AGC in 2002. In 2003, NO_3-N was significantly higher after peas (PEA) in 30-60 cm. Until spring, soil NO_3-N increased in both years, with the significantly lowest soil content after winter wheat in both profiles. At crop emergence, up to 187 (2003) and 132 kg NO_3-N ha^{-1} (2004), respectively, were found after PEA in 0-60 cm. While in 2003 a similarly high level was recorded after AGC, it was substantially lower in 2004. Until mid/end July, soil was more or less depleted from nitrate-N in both years, rising slightly until final harvest only in 2003 (Fig. 3.2a,b).

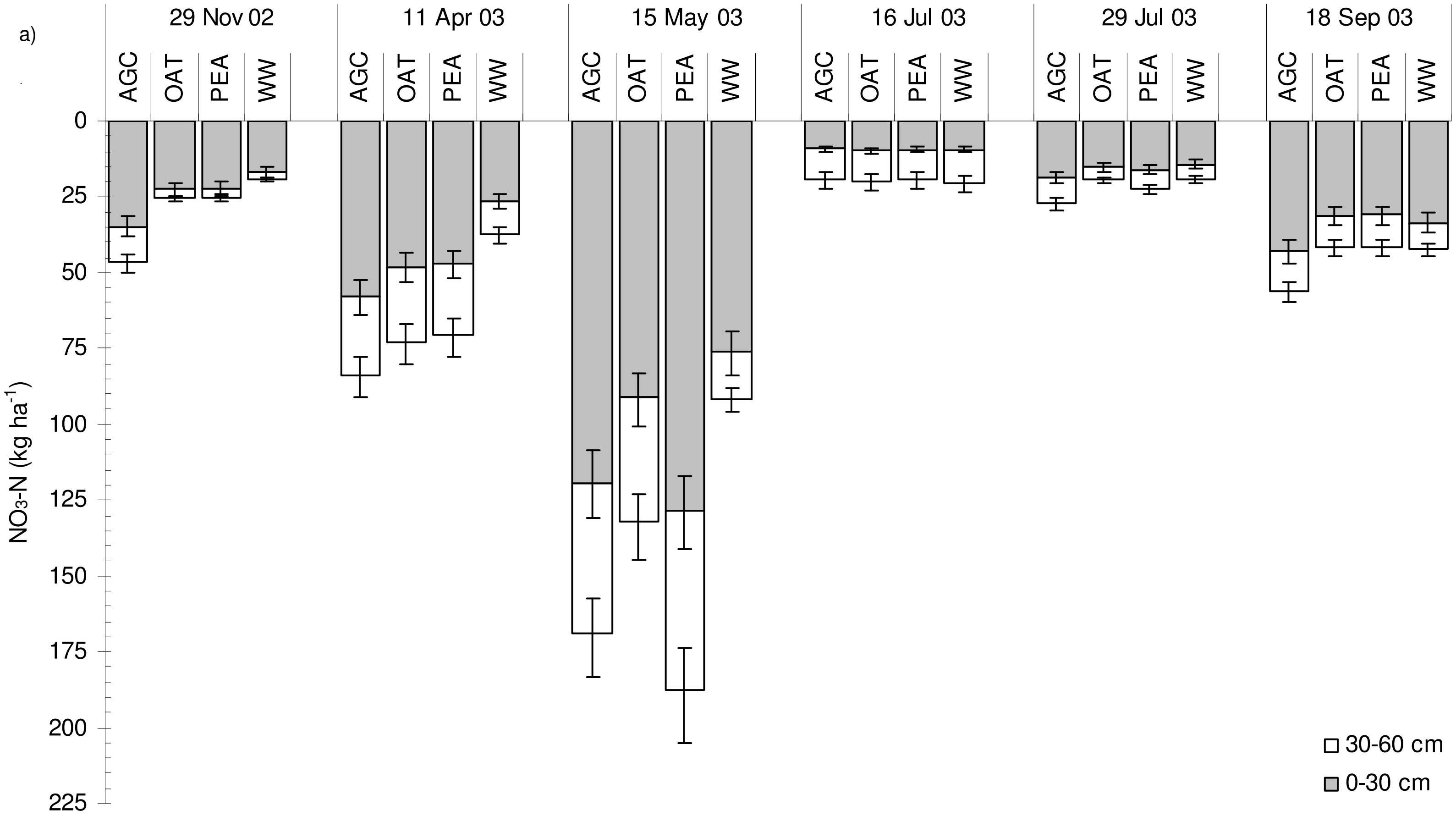

Figure 3.2: Course of nitrate-N in soil profiles 0-30 and 30-60 cm as affected by preceding crop in the experimental seasons in (a) 2002-2003 and (b) 2003-2004. Medians and their 95 % confidence limits

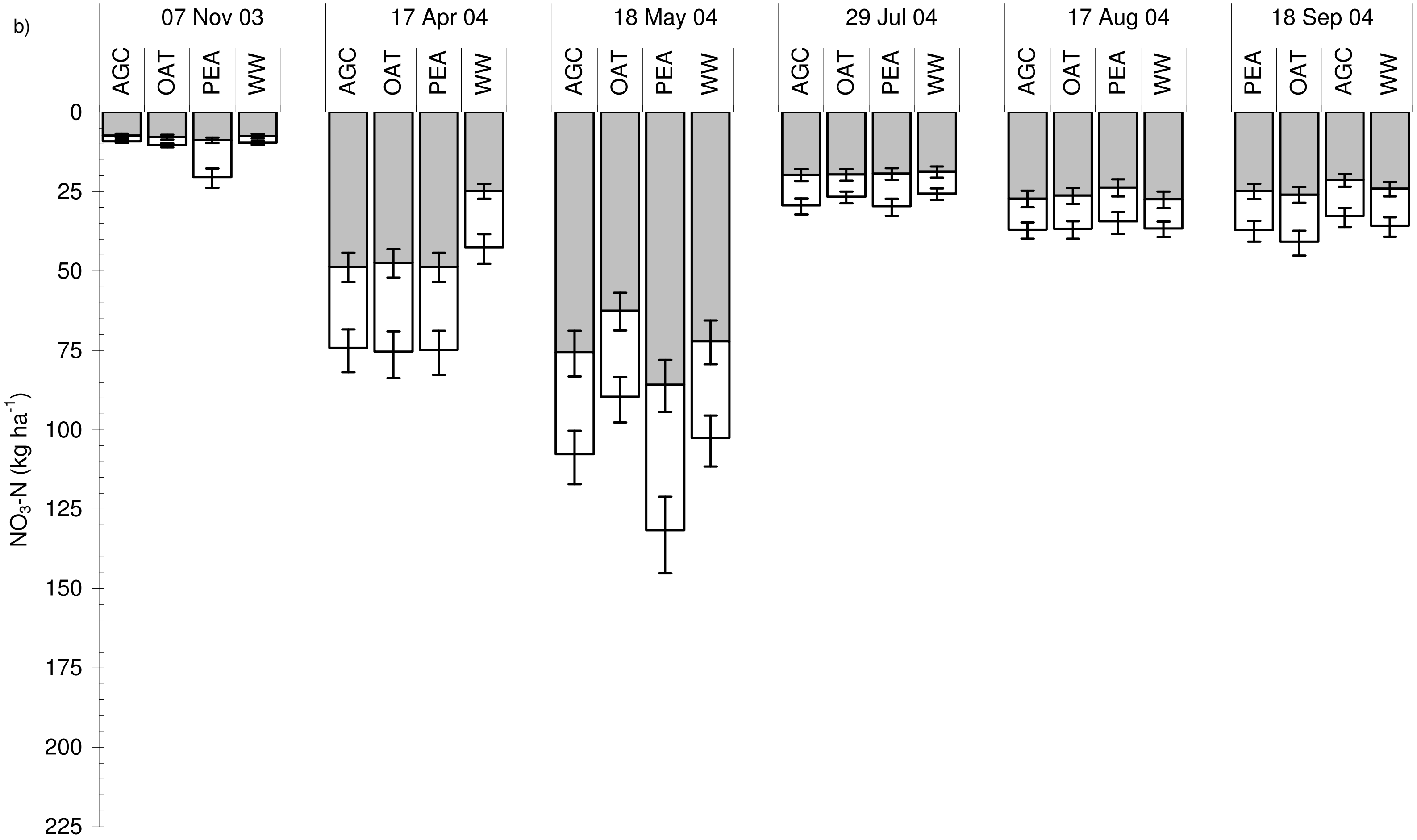

Figure 3.2 continued

Preceding cropping significantly ($P < 0.05$) affected crop development only in 2003 when, after leguminous preceding crops, plants developed slightly faster than after cereal grains (data not shown). However, no significant interactions of preceding crop with other treatments were established. Therefore data are presented as means of all preceding crops tested and Figure 3.3a,b show the interaction of factors CV•PS•TIME. Significant interactions were established for PS•TIME and CV•PS in both years and for CV•PS•TIME in 2004. In 2003, pre-sprouted Marlen developed much faster than when not pre-sprouted, which, on the other hand, developed simultaneously to pre-sprouted Agria. As the season proceeded, the positive response of crop development to pre-sprouting vanished (Fig. 3.3a).

On 29 May, 2004, not pre-sprouted Agria had still not emerged. In comparison, cv. Marlen developed much quicker than Agria, whereas both cultivars developed similarly rapidly when pre-sprouted. Around 25 June, crops of all treatments except not pre-sprouted Agria were flowering, while one week later, these differences were hardly detectable anymore, and vanished completely by mid-July (Fig. 3.3b). Overall, all treatments reached growth stage BBCH 69 (end of flowering) at around the same time, and subsequently they developed analogously.

At the two early harvests, the canopies of all treatments were at the same above-ground growth stage in both experimental seasons (data not shown).

In Tables 3.3 and 3.4 the results from statistical analysis as described in Material and Methods for the parameters examined and discussed are presented. Subsequently, however, only the relevant comparisons of means are described in results, i.e. when significance of treatment effects and/or their interactions was established.

Table 3.3: P-values for Wald tests of sources of variation for different crop growth parameters at the end of July in (a) 2003 and (b) 2004

(a) 2003	Numerator d.f.	Canopy DM	Tuber DM	Total crop DM	Ratio canopy/ tuber DM	Canopy N uptake	Tuber N uptake	Total crop N uptake	Ratio canopy /tuber N uptake	N utilization efficiency
PC	3	**<.0001**	**0.0311**	**0.0010**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**0.0003**
PS	1	**<.0001**	**<.0001**	**0.0186**	**<.0001**	**<.0001**	**0.0001**	0.1156	**<.0001**	**0.0170**
CV	1	**0.0006**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	0.1329	**<.0001**	**<.0001**
PC•PS	3	0.8375	0.2358	0.2981	0.4797	0.1064	0.0758	0.0781	0.3286	0.4881
PC•CV	3	0.4702	**0.0031**	**0.0040**	0.0628	0.3448	**0.0034**	0.3660	**0.0152**	0.2072
CV•PS	1	0.0710	0.2362	0.1002	0.5457	0.6889	0.9855	0.7867	0.1604	0.8309
PC•CV•PS	3	0.3851	0.1964	0.2931	0.2994	0.4634	0.2205	0.7127	0.2326	0.3412
REP	3	0.1269	**0.0032**	**0.0050**	0.3249	0.5136	**0.0161**	0.0872	0.1736	0.4577
(b) 2004										
PC	3	**<.0001**	**0.0092**	**<.0001**	**0.0024**	**<.0001**	**<.0001**	**0.0163**	0.1535	0.0500
PS	1	**0.0148**	**<.0001**	0.2126	**<.0001**	**<.0001**	**<.0001**	**0.0017**	**<.0001**	**<.0001**
CV	1	**0.0005**	**<.0001**	0.4085	**<.0001**	**<.0001**	**<.0001**	**0.0233**	**<.0001**	0.9377
PC•PS	3	0.4509	0.6522	0.8429	0.9858	0.7717	0.4615	0.1690	0.7171	0.2055
PC•CV	3	0.4671	0.5322	0.2444	0.2224	0.2335	0.8369	**0.0007**	0.1295	0.7020
CV•PS	1	0.8234	0.1203	0.7371	0.1840	0.0841	0.6301	0.5624	0.8863	0.4904
PC•CV•PS	3	0.3073	0.5385	0.5321	0.6762	0.8010	0.8964	0.1075	0.6725	0.4199
REP	3	0.2746	0.9546	**0.0380**	0.6529	0.0997	**<.0001**	0.9808	0.3151	**0.0206**

P-values in bold represent significant effects at the 5 % level.

Table 3.4: P-values for Wald tests of sources of variation for different crop growth parameters at the end of July in (a) 2003 and (b) 2004

Source of variation	d.f.[1]	Tuber FM yield	Tuber FM yield < 40 mm	Tuber FM yield 40-65 mm	Tuber FM yield > 65 mm	% of tuber yield < 35 mm in total FM yield	% of tuber yield 35-50 mm in total FM yield	% >50mm in FM yield (>35 mm)	Tubers m^{-2}	Average tuber weight
(a) 2003										
REP	3	**0.0013**	0.0704	**0.0032**	0.0989	**0.0238**	**0.0448**	**0.0280**	0.4320	0.2247
Preceding crop (PC)	3	**<.0001**	0.1573	**0.0003**	**0.0001**	**0.0323**	**0.0004**	**0.0005**	0.2331	**0.0167**
Cultivar (CV)	1	0.6720	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**0.0011**	**0.0466**	**0.0322**
PC•CV	3	0.5081	0.2638	0.2393	0.1993	0.6701	0.4662	0.4218	0.1211	0.4170
Pre-sprouting (PS)	1	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
vPC•PS	3	**0.0390**	0.6025	0.7454	0.1562	0.9927	0.7776	0.8243	0.9721	0.3397
CV•PS	1	0.2781	**<.0001**	0.4071	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**0.0080**	**0.0044**
PC•CV•PS	3	0.4697	0.3852	0.6599	0.3477	0.3353	0.2999	0.2391	0.3496	0.1342
HAR•TIME	2	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	0.7251	**<.0001**
PC•HAR•TIME	6	**0.0193**	0.8166	0.3828	**0.0036**	0.7653	0.2344	0.3521	0.1603	0.1123
CV•HAR•TIME	2	**<.0001**	**0.0028**	**<.0001**	**<.0001**	**<.0001**	**0.0005**	**0.0009**	**0.0064**	**0.0193**
PS•CV•HAR•TIME	6	**0.0021**	0.2843	**0.0380**	0.5938	0.6689	0.9581	0.9019	0.1078	0.2685
PS•HAR•TIME	2	**0.0359**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**0.0174**	**0.0008**	**<.0001**	**<.0001**
PC•PS•HAR•TIME	6	0.5604	0.8062	0.8279	0.4917	0.6877	0.2655	0.2395	0.3683	0.4757
CV•PS•HAR•TIME	2	0.4793	0.3227	**0.0073**	**0.0005**	**<.0001**	0.0536	0.4088	**0.0425**	0.1042
PC•CV •PS•HAR•TIME	6	0.4163	0.4088	0.5649	0.7398	0.7414	0.1901	0.2200	0.2757	0.2188
(b) 2004										
REP	3	**0.0430**	0.1471	**0.0357**	**0.0181**	**0.0021**	**<.0001**	**<.0001**	0.9719	**0.0301**
Preceding crop (PC)	3	**<.0001**	0.9570	**<.0001**	0.1712	**0.0122**	**<.0001**	**<.0001**	0.1942	**0.0015**
Cultivar (CV)	1	**0.0481**	**0.0003**	**<.0001**	0.7669	**<.0001**	**0.0094**	0.2852	**<.0001**	**<.0001**
PC•CV	3	0.5265	0.7110	0.1392	0.2680	0.0824	**0.0224**	**0.0335**	0.6708	0.9241
Pre-sprouting (PS)	1	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**0.0408**	**<.0001**
PC•PS	3	0.2234	0.6815	0.7336	0.4249	0.1697	0.1271	0.1338	0.2704	0.9888
CV•PS	1	0.6657	0.7337	0.4126	**0.0374**	**0.0397**	0.1216	0.3347	0.1074	0.7248
PC•CV•PS	3	0.5531	0.9188	0.5914	0.7513	0.6953	0.6605	0.6472	0.5880	0.2315
HAR•TIME	2	**<.0001**	**0.0004**	**<.0001**	0.6701	**<.0001**	**0.0297**	**0.0059**	0.7692	0.1061
PC•HAR•TIME	6	0.1199	0.4637	0.3096	0.6690	0.8273	0.7252	0.7767	0.6951	0.6686
CV•HAR•TIME	2	0.0985	**0.0267**	0.5015	0.1129	0.8047	0.1790	0.1855	**0.0001**	**0.0006**
PS•CV•HAR•TIME	6	0.2440	0.2266	0.2064	0.3196	0.2990	0.5176	0.3725	**0.0466**	0.3019
PS•HAR•TIME	2	0.9272	0.7227	0.8291	0.6156	0.0949	0.1863	0.2645	**0.0379**	0.0915
PC•PS•HAR•TIME	6	0.6451	0.9921	0.9077	0.5381	0.4396	0.7740	0.8115	0.5019	0.6382
CV•PS•HAR•TIME	2	0.2092	0.9782	0.0939	0.6274	0.4169	0.9123	0.9235	0.1674	0.1744
PC•CV •PS•HAR•TIME	6	0.4273	0.4202	0.3735	0.8851	0.5238	0.5985	0.5892	0.1446	0.0914

[1] Numerator degrees of freedom; P-values in bold represent significant effects at the 5 % level

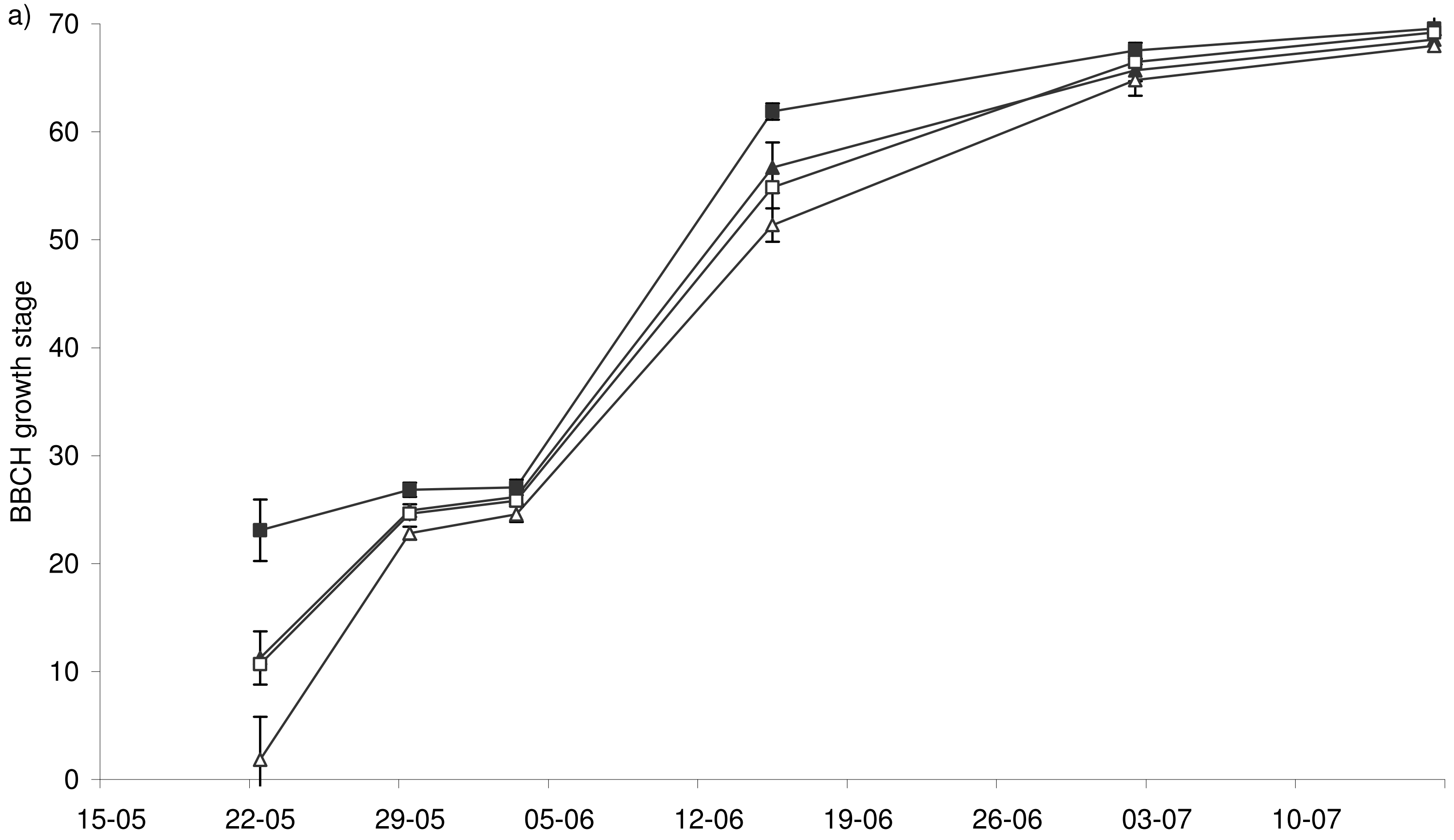

Figure 3.3: Potato crop growth stages according to Hack et al. (1993) as affected by cultivar and presprouting in (a) 2003 and (b) 2004. Mean values represent data over all precrops and both, early and final harvest plots; means ± standard deviation [n=32 (2003) and n=40 (2004)]. ▲ = Agria presprouted; △ = Agria not-presprouted; ■ = Marlen presprouted; □ = Marlen not-presprouted

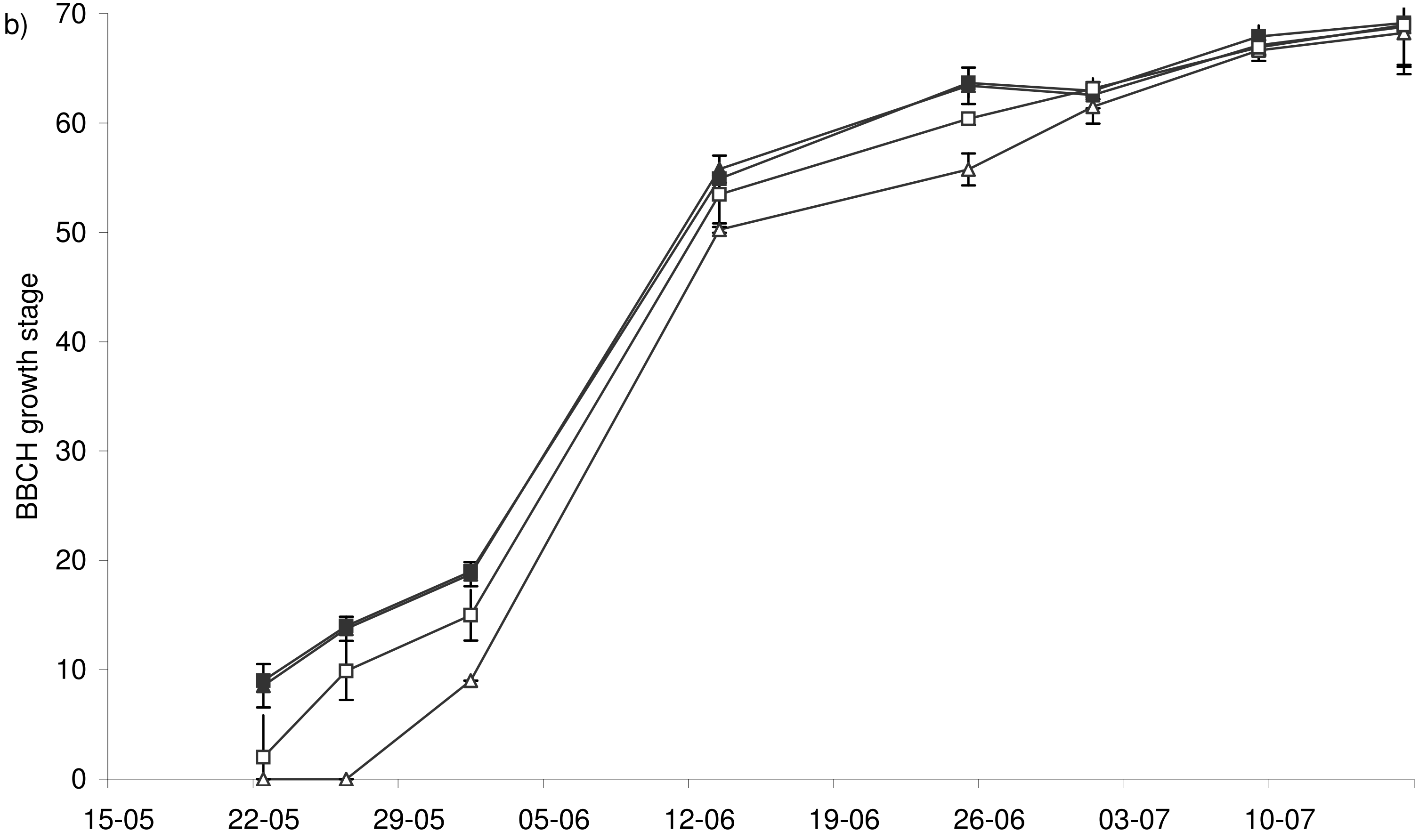

Figure 3.3 continued

3.3.1 Canopy and tuber DM at the end of July

In both years, total above-ground canopy dry matter (leaves and stems; CDM) at the end of July was significantly affected by preceding crop, pre-sprouting and cultivar (Table 3.3). In 2003, highest canopy DM was measured after AGC (2.8 t DM ha^{-1}) and PEA (2.5 t DM ha^{-1}), while both cereals gave significantly lower and comparable CDM (on average 1.7 t DM ha^{-1}). In both seasons pre-sprouting and cv. Marlen showed significantly lower CDM (Table 3.5). In 2004, CDM after OAT (1.7 t DM ha^{-1}) was lower than after WW (1.9 t DM ha^{-1}) and the difference between PEA (2.4 t DM ha^{-1}) and AGC (2.2 t DM ha^{-1}) was insignificant.

Tuber dry matter (TDM) at the end of July in both seasons was mainly affected by cultivar and pre-sprouting, and less by preceding crop. Pre-sprouting had the strongest impact in 2004 (Table 3.3). After every preceding crop, TDM of cv. Marlen was higher than for cv. Agria, but the increase amounted to + 30 % (after legumes) and + 11 % (after cereals). When seed-tubers were pre-sprouted, TDM amounted to + 10 % (2003) and + 16 % (2004). In 2004, average TDM was appreciably lower than in the season before and it was only after PEA that it differed significantly from the other preceding crops (Table 3.5).

In 2003, total crop dry matter at the end of July (canopy and tubers; CTDM) of cv. Marlen was significantly higher only after the two leguminous preceding crops, but not after cereals. Pre-sprouting increased CTDM significantly by 0.4 t DM ha^{-1} on average of both cultivars. In 2004, CTDM was significantly influenced only by preceding cropping, pre-sprouting and cultivar. CTDM after AGC was significantly higher than after OAT (6.7 t DM ha^{-1}), but the difference between OAT and WW (6.5 t DM ha^{-1}) was insignificant (Table 3.5).

3.3.2 Ratio canopy/tuber DM

The ratio of CDM to TDM was consistently and signifcantly affected by preceding crop, presprouting and cultivar (Table 3.3). In 2003, the CDM/TDM-ratio ranged between 0.39 for AGC, 0.32 for PEA, 0.26 for OAT and 0.23 for WW. The ratio of cv. Agria (0.34) was appreciably higher than that for cv. Marlen (0.25). When seed was pre-sprouted, the ratio was significantly lower, namely 0.26 instead of 0.34 (Table 3.5d). In 2004, the average ratio was higher than in the previous season and ranged between 0.46 (AGC and PEA, respectively), 0.42 (WW) and 0.36 (OAT). Only the difference between OAT and PEA was significant. As in 2003, but even more markedly, pre-sprouting decreased the ratio (0.35 instead of 0.50). Again, the ratio of cv. Agria was significantly higher than that of Marlen (0.50 instead of 0.35) (Table 3.5d).

At the end of July, tuber DM yield correlated highly with total crop dry matter (R^2 = 0.81 and 0.70 in 2003 and 2004, respectively) and so did tuber FM yield (R^2 = 0.84 and 0.69, respectively). The corresponding equations were: $y = -0.24 + 0.80x$; $y = -1.05 + 0.86x$; $y = 6.52 + 2.51x$; $y = 2.12 + 80x$.

3.3.3 Canopy and tuber N uptake until the end of July

Canopy N uptake (CNU) was consistently and signifcantly affected by preceding crop, presprouting and cultivar (Table 3.3). In 2003, CNU of cv. Agria was by 15 kg N ha^{-1} higher compared with cv. Marlen. The canopy from pre-sprouted seed-tubers removed 12 kg N ha^{-1} less than when not prepared. Depending on preceding crop, CNU ranged between 76 for AGC, 53 for PEA, 36 for OAT and 32 kg N ha^{-1} for WW (Table 3.6a). All mean values differed significantly, except those for OAT and WW. In 2004, CNU was lower (- 14 kg N ha^{-1}) when seed-tubers were pre-sprouted. For both cultivars, CNU was highest after PEA and did not differ between AGC and WW, but was significantly lower after OAT. After cereals, however, CNU was 45 % higher for cv. Agria compared to cv. Marlen, the relative differences between the two cultivars being smaller after PEA (17 %) and AGC (10 %).

Tuber N uptake (TNU) was consistently and signifcantly affected by preceding crop, presprouting and cultivar, with only one significant interaction for PC•CV in 2003 (Table 3.3). TNU until the end of July 2003 did not differ between the two leguminous crops (90 and 89 kg N ha^{-1}, respectively), but it was significantly lower (69 and 68 kg N ha^{-1}, respectively) after both cereals. Tubers of cv. Marlen removed significantly more N, yet the relative difference in N uptake between the two cultivars was larger after legumes (25 and 26 % after legumes) as compared to cereal grains (17 and 16 %, respectively). Progeny tubers from pre-sprouted seed removed appreciably more N (+ 8 kg N ha^{-1} or + 10 %). This was also the case for the year 2004 (+ 6 kg N ha^{-1} or + 11 %), when average TNU was lower than in 2003 (Table 3.4b). In 2004, the differentiation between preceding crops was much less profound. Only TNU after PEA differed significantly from the other preceding crops (Table 3.6).

In 2003, total canopy and tuber N uptake (CTNU) until the end of July was only influenced by preceding cropping (Table 3.3). After AGC, potato crops recovered 166 kg N ha^{-1}, PEA 142 kg N ha^{-1}, and cereal grains 105 and 99 kg N ha^{-1}, respectively. In 2004, the strongest impact was established for pre-sprouting and preceding cropping, followed by cultivar (Table 3.3). Significant differences were found between PEA 131 (kg N ha^{-1}) and AGC (117 kg N ha^{-1}), while CTNU after AGC did not differ from WW (107 kg N ha^{-1}), but from OAT (97 kg N ha^{-1}). N recovery of pre-sprouted crops was significantly lower, at 7 kg N ha^{-1} (Table 3.6).

3.3.4 Ratio canopy/tuber N uptake

After every preceding crop, cv. Agria displayed a higher ratio of canopy N uptake to tuber N uptake (CNU/TNU) in 2003 than cv. Marlen, but the ratio of cv. Agria was 42-46 % higher after legumes, compared with only 34-36 % higher after cereal grains (Table 3.6). In 2004, pre-sprouting gave a much lower ratio than not pre-sprouted seed (0.53 instead of 0.74). The ratios ranged between 0.83 (WW), 0.86 (OAT), 0.98 (PEA) and 1.00 (AGC), but only the difference between OAT and PEA was significant (Table 3.6).

N utilization efficiency

Nitrogen utilization efficiency (NUE) was consistently (both seasons) affected by pre-sprouting, but also by preceding crop and cultivar in 2003 (Table 3.3). In 2003, highest NUE was established after cereals (0.34 and 0.35 t DM kg^{-1} N ha^{-1}, respectively), which was significantly higher than after PEA (0.30 t DM kg^{-1} N ha^{-1}), while significantly lowest NUE was obtained after AGC (0.24 t DM kg^{-1} N ha^{-1}) (Table 3.6). NUE of cv. Agria was significantly higher (0.32) than for cv. Marlen (0.29). Pre-sprouting increased NUE in both years, the impact being much more marked in 2004. In that year, NUE was significantly lower after legumes compared to cereals. Comparing the two years, NUE in 2003 (0.30) was higher than in the following season (0.25).

Table 3.5: The effect of preceding crop (PC), cultivar (CV) and pre-sprouting (PS) upon DM of canopy (a), tubers (b), the total crop (c) and the ratio of canopy/tuber DM (d) at the end of July in 2003 and 2004 (values are presented as mean)

			(a) Canopy (t DM ha^{-1})		(b) Tubers (t DM ha^{-1})		(c) Canopy + tubers (t DM ha^{-1})		(d) Ratio canopy DM/ tuber DM	
PC	CV	PS	2003	2004	2003	2004	2003	2004	2003	2004
Peas	Agria	yes	2.5	2.4	7.6	5.5	10.1	7.9	0.33	0.44
		no	2.6	2.6	6.3	4.2	8.8	6.8	0.41	0.63
	Marlen	yes	2.1	2.1	9.7	6.3	11.8	8.4	0.22	0.34
		no	2.7	2.4	8.4	5.5	11.1	8.0	0.32	0.44
Oats	Agria	yes	1.8	1.7	7.5	5.0	9.4	6.7	0.25	0.35
		no	2.1	2.1	6.4	3.8	8.5	5.9	0.32	0.54
	Marlen	yes	1.5	1.2	7.5	5.8	9.1	7.0	0.20	0.21
		no	2.0	1.7	7.9	5.1	9.9	6.8	0.25	0.34
Alfalfa-grass-clover	Agria	yes	2.7	2.2	7.0	5.2	9.7	7.3	0.39	0.42
		no	3.1	2.3	6.0	4.1	9.0	6.5	0.52	0.58
	Marlen	yes	2.5	1.9	8.7	5.7	11.2	7.6	0.29	0.34
		no	2.9	2.4	8.0	5.0	10.9	7.3	0.36	0.48
Winter wheat	Agria	yes	1.6	2.1	7.0	4.7	8.7	6.8	0.23	0.44
		no	2.0	2.4	6.5	4.0	8.5	6.4	0.30	0.59
	Marlen	yes	1.2	1.4	8.0	5.6	9.2	7.0	0.15	0.25
		no	1.7	1.9	7.1	4.9	8.8	6.8	0.24	0.39
	2003	2004								
S.E.D*/ d.f.	PC	PC/CV	0.18/38.5	0.02/38.8	0.44/43.4	0.28/42.2	0.52/40.5	0.42/44.9	0.02/44.7	0.05/42.3
	CV/PS	PS	0.17/36.0	0.02/24.0	0.43/36.0	0.25/24.0	0.49/36.0	0.42/24.0	0.03/36.0	0.04/24.0

* The standard errors of a difference and the corresponding denominator degrees of freedom (d.f.) (following slash) are relevant for comparison of means of, e.g., preceding crops (PC; 2003) at a given combination of the factors cultivar and pre-sprouting, respectively. Note that - depending on the year – the S.E.D. and d.f. are allocated to different factors. Factors CV and PS (2003) and PC and CV (2004) share the same S.E.D. and d.f. Denominator d.f. were approximated by the Kenward-Roger method and may vary among years and traits.

Table 3.6: The effect of preceding crop (PC), cultivar (CV) and pre-sprouting (PS) upon N uptake by canopy (a), tubers (b), total crop (c), the ratio of canopy/tuber N uptake at the end of July (d) and N utilization efficiency (e) in 2003 and 2004 (values are presented as mean)

			(a) Canopy N uptake (kg N ha^{-1})		(b) Tuber N uptake (kg N ha^{-1})		(c) Total N uptake (kg N ha^{-1})		(d) Ratio canopy/ tuber N uptake		(e) N utilization efficiency	
PC	CV	PS	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
Peas	Agria	yes	58.9	63.0	82.2	67.3	141.1	130.3	0.72	0.95	0.32	0.26
		no	64.0	74.1	68.6	57.6	132.6	131.7	0.94	1.32	0.32	0.22
	Marlen	yes	37.4	51.9	111.1	75.5	148.5	127.4	0.34	0.69	0.27	0.26
		no	51.5	65.4	93.3	67.9	144.7	133.2	0.56	0.97	0.26	0.21
Oats	Agria	yes	36.6	44.5	67.5	53.0	104.0	97.5	0.56	0.86	0.36	0.28
		no	46.2	58.5	57.6	45.3	103.8	103.8	0.81	1.31	0.36	0.24
	Marlen	yes	26.6	26.7	74.5	60.6	101.0	87.3	0.36	0.44	0.34	0.31
		no	33.8	44.3	76.5	54.8	110.3	99.1	0.44	0.81	0.29	0.23
Alfalfa-grass-clover	Agria	yes	75.0	56.0	80.2	60.3	155.2	116.4	0.94	0.93	0.28	0.26
		no	96.1	65.1	74.4	53.1	170.6	118.2	1.29	1.25	0.24	0.23
	Marlen	yes	58.2	47.9	105.4	64.6	163.6	112.5	0.55	0.75	0.24	0.25
		no	74.7	62.7	100.3	59.6	175.0	122.3	0.75	1.06	0.21	0.22
Winter wheat	Agria	yes	34.5	55.3	62.4	53.8	96.9	109.1	0.55	1.03	0.36	0.28
		no	42.5	64.8	61.4	51.2	103.8	116.0	0.69	1.28	0.34	0.23
	Marlen	yes	19.1	31.8	77.8	62.3	96.8	94.0	0.25	0.51	0.34	0.27
		no	30.4	51.6	68.8	57.8	99.2	109.3	0.45	0.89	0.34	0.23
	2003	2004										
S.E.D*/ d.f.	PC	PC/CV	5.45/36.8	5.67/36.2	5.38/32.8	3.88/38.7	8.92/28.0	7.41/34.8	0.06/45.0	0.11/41.1	0.02/31.0	0.02/38.0
	CV/PS	PS	4.91/36.0	4.31/24.0	4.63/36.0	3.17/24.0	7.20/36.0	5.37/24.0	0.07/36.0	0.10/24.0	0.02/36.0	0.01/24.0

* The standard errors of a difference and the corresponding denominator degrees of freedom (following slash) are relevant for comparison of means of e. g. preceding crops (PC) at a given combination of the factors cultivar and pre-sprouting, respectively. Note that - depending on the year – the S.E.D. and d.f. are allocated to different factors. Factors CV and PS (2003) and PC and CV (2004) share the same S.E.D. and d.f. Denominator d.f. were approximated by the Kenward-Roger method and may vary among years and traits.

3.3.5 Tuber yield

Fresh matter yield

In 2003, cv. Marlen had higher tuber fresh matter yields (TFM) than cv. Agria in most cases at the two early harvests, while the latter gave higher yields at final harvest (Table 3.7). Between first and second early harvest, the absolute and relative increase in TFM of cv. Agria was higher after cereals compared to legumes. Subsequently, it was cv. Agria that showed higher absolute and relative yield increases – independent of preceding crop (Table 3.7). The increase in yield rendered by pre-sprouting at first, second and final harvest was + 2.7, 2.6 and 0.9 t FM ha^{-1}, at which the latter increase was insignificant. While at the end of July 2004, TFM after PEA was significantly higher, crops after AGC and WW had compensated the margin by final harvest in September, due to a relative yield increase of 7 and 13 %, respectively. Consequently, only after OAT was TFM significantly lowest. The positive response of TFM to pre-sprouting lasted throughout the growing season. At harvest in September, it still amounted to + 2.6 t ha^{-1} as compared to + 2.8 t ha^{-1} at the end of July (Table 3.7).

Tuber yield for crisps processing

The demanded tuber size-grade for raw material for processing into crisps is 40-65 mm. In 2003, pre-sprouted seed-tubers gave lower yields < 40 mm, but the response was only significant for cv. Agria. This effect of pre-sprouting was established only at early harvests, when cv. Agria still yielded significantly more tubers < 40 mm than cv. Marlen. In 2004, it was again pre-sprouting that reduced tuber FM yield < 40 mm, but independently of the time of assessment. In contrast to 2003, cv. Agria on average yielded less tubers graded < 40 mm, and the difference between the two cultivars became smaller as the season proceeded (Table 3.8).

While the positive response of marketable tuber yield for crisps (40-65 mm) to pre-sprouting amounted to 5.0 t ha^{-1} (+ 36 %) in mid-July 2003, it decreased within the following two weeks (+ 2.8 t ha^{-1} or + 11 %) to become insignificant at final harvest. The initially lower (- 2.9 t ha^{-1}) marketable yield of cv. Agria at first harvest was compensated by September, when cv. Agria yielded 1.3 t ha^{-1} more than cv. Marlen (Table 3.6). In 2004, final marketable tuber yield (25.6 t ha^{-1}) after PEA was significantly highest compared to the other preceding crops. The positive response to pre-sprouting at subsequent harvests amounted to 4.0 (20 %), 3.8 (17 %) and 3.6 t ha^{-1} (16 %).

In mid-July 2003, pre-sprouted Agria was the only treatment giving an appreciable amount of tubers > 65 mm, namely 0.4 t ha^{-1}. At final harvest, pre-sprouted Agria gave 5.7 t ha^{-1} of tubers > 65 mm, which was significantly more than the three other factorial combinations, which did not differ from each other (Table 3.8). In 2004, the significant increase (average of all harvests) in TFM graded > 65 mm due to pre-sprouting amounted to + 0.8 t ha^{-1} (+ 200 %) for cv. Agria and + 0.3 t ha^{-1} (+ 56 %) for cv. Marlen.

Tuber yield for French fry processing

At the time the present study was conducted, tuber raw material for organic French fries was only marketable when tubers were graded at least 35 mm, of which 60% should be larger than 50 mm. A significant impact on the size grade > 50 mm was exerted by the cultivar, pre-sprouting and harvest time in both seasons (Table 3.4). Pre-sprouting reduced the percentage of under-sized tuber yield, but the effect became smaller as the season proceeded in 2003, while in 2004, the response remained significant until final harvest. The highest percentage of tuber yield < 35mm was obtained after WW (2003) and after OAT (2004), respectively (Table 3.9a).

Significantly higher portions of the medium-sized tuber yield (35-50 mm) at final harvest in 2003 were obtained after leguminous preceding crops. When seed-tubers were pre-sprouted, the percentage of this tuber size grade was 46 instead of 35 % (of total yield) in 2003 and 63 instead of 52 % in 2004. While in 2003 cv. Marlen yielded a higher portion (44 %) than cv. Agria (38 %) in September, there were no differences between the two cultivars at final harvest in the following season. In 2003, a marked reduction in the portion of tuber yield (35-50 mm) was established over time (subsequent harvests), whereas in 2004 there was no clear tendency towards a response to harvest time (Table 3.9).

The portion of tuber yield > 50 mm in tuber yield > 35 mm (P50[35]) in 2003 was most significantly influenced by harvest time and pre-sprouting, and less by cultivar and preceding cropping (Table 3.4). P50[35] at final harvest was highest after leguminous preceding crops (on average 63 %), compared to cereals (56 and 52 %, respectively). When P50[35] was assessed at the end of July, 55 % (pre-sprouted) of tuber yield (> 35 mm) was larger than 50 mm, compared with 37 % (not pre-sprouted). At final harvest, the threshold of 60 % was exceeded only by the pre-sprouted crops. The increase in P50[35] due to pre-sprouting was much more marked for cv. Agria, explaining the significant interaction of CV•PS. In 2004, only the main treatments were significant, and pre-sprouting in this year exerted the most profound effect on P50[35]. P50[35] responded positively to pre-sprouting (46 instead of 32 %). Yet, not even until final harvest was the threshold reached. In that season, the impact of the cultivar was negligible ($P < 0.034$). P50[35] was significantly highest (45 %) after PEA as preceding crop (Table 3.9).

3.3.6 Tuber yield components

In 2003, pre-sprouting gave reduced tuber density (tubers m^{-2}) at the two early harvests, but no differences were measured at final harvest. In 2004, crops of cv. Marlen produced 40, as compared to cv. Agria (33 tubers m^{-2}), even though the difference was significant only at one of the earlier harvests (Table 3.10). In both seasons, preceding crop did not have an effect on tuber density (Table 3.4).

Average tuber weight (ATW) in 2003 was mainly affected by harvest time and pre-sprouting, but also by preceding cropping and cultivar (Table 3.4). The strongest interaction was established for PS•HAR•TIME, as the positive response to pre-sprouting was more marked the earlier the harvest was conducted. In 2003, the effect amounted to an increase in ATW of + 35, + 27 and + 2 % at subsequent harvests, corresponding to + 17, + 18 and + 2 g. ATW of cv. Agria was significantly higher only at final harvest 2003, whereas in 2004 cv. Marlen gave lower ATW, regardless of the time of assessment (Table 3.10).

Table 3.7: The effect of preceding crop (PC), cultivar (CV) and pre-sprouting (PS) and harvest time (HAR•TIME) on tuber FM yield (t ha^{-1}) at subsequent harvest in 2003 and 2004.

			Tuber FM yield (t ha^{-1})					
				2003			2004	
PC	CV	PS	15 July	28 July	17 September	28 July	13 August	9 September
Peas	Agria	yes	24.4	33.7	45.3	33.5	35.3	31.2
		no	20.5	28.0	42.5	28.9	29.1	28.6
	Marlen	yes	26.4	37.1	39.7	32.8	32.8	32.8
		no	23.2	33.5	38.0	28.0	29.6	30.6
Oats	Agria	yes	22.4	31.9	37.2	26.7	28.8	27.3
		no	18.5	28.1	37.6	24.4	26.3	25.5
	Marlen	yes	24.0	28.9	33.8	26.4	28.7	27.8
		no	21.3	30.3	32.4	23.2	26.3	23.0
Alfalfa-grass-clover	Agria	yes	23.1	31.5	41.9	29.4	30.4	31.3
		no	20.1	28.0	40.0	26.7	27.6	28.8
	Marlen	yes	22.6	33.8	38.3	27.2	28.9	30.5
		no	20.9	31.5	36.9	27.0	28.1	27.5
Winter wheat	Agria	yes	20.4	29.1	35.1	30.1	29.7	30.3
		no	19.3	28.6	35.8	26.4	27.4	29.3
	Marlen	yes	22.7	30.2	32.7	24.9	28.7	31.8
		no	20.6	27.6	33.4	24.4	25.7	28.7
S.E.D./d.f.		PC		1.46/112			1.59/80.6	
		HAR•TIME		1.48/75.0			1.46/69.6	
		CV/PS		1.36/82.2			1.36/68.4	

[1] The standard errors of a difference are relevant for comparison of means of, e.g. preceding crops (PC) at a given combination of the factors cultivar (CV), pre-sprouting (PS) and harvest time (HAR•TIME). Denominator degrees of freedom were approximated by the Kenward-Roger method and may vary among years.

Table 3.8: The effect of preceding crop (PC), cultivar (CV) and presprouting (PS) and harvest time (HAR•TIME) on graded tuber yield (t ha^{-1}) relevant for crisps production at subsequent harvests in 2003 and 2004

			Tuber FM yield < 40 mm (t ha^{-1})						Tuber FM yield 40-65 mm (t ha^{-1})						Tuber FM yield > 65 mm (t ha^{-1})					
			2003			2004			2003			2004			2003			2004		
PC	CV	PS	15-07	28-07	17-09	28-07	13-08	09-09	15-07	28-07	17-09	28-07	13-08	09-09	15-07	28-07	17-09	28-07	13-08	09-09
Peas	Agria	yes	3.8	2.0	2.3	3.9	2.4	3.1	19.6	29.0	35.1	28.0	31.2	26.4	1.0	2.8	7.9	1.7	1.7	1.8
		no	7.7	4.1	3.5	4.9	4.6	4.0	12.9	23.9	36.7	23.7	24.1	23.8	0.0	0.1	2.3	0.4	0.4	0.8
	Marlen	yes	4.0	3.2	2.7	4.0	4.0	7.9	22.3	33.3	34.8	27.4	27.5	28.2	0.1	0.5	2.2	1.5	1.3	0.5
		no	4.8	3.0	3.1	5.6	4.1	8.6	18.4	30.2	34.0	21.9	24.5	24.1	0.0	0.4	0.9	0.5	0.9	0.6
Oats	Agria	yes	3.9	3.2	2.2	4.0	3.5	3.1	18.3	27.3	29.9	21.8	24.7	23.1	0.1	1.3	5.0	0.9	0.6	1.1
		no	7.3	5.3	4.2	5.4	4.2	4.4	11.2	22.8	32.6	18.8	22.0	20.9	0.0	0.0	0.8	0.2	0.1	0.2
	Marlen	yes	3.9	2.5	2.8	4.6	4.0	4.3	20.1	26.1	29.8	21.2	23.3	22.7	0.1	0.2	1.3	0.6	1.4	0.8
		no	5.4	3.3	2.3	6.0	5.2	5.7	15.9	27.0	29.5	17.0	20.4	17.0	0.0	0.1	0.6	0.2	0.8	0.4
Alfalfa-grass-clover	Agria	yes	4.1	2.6	2.2	3.6	2.6	2.8	18.5	26.5	32.5	24.7	27.0	26.5	0.5	2.4	7.3	1.1	0.8	1.3
		no	7.2	4.4	3.2	6.0	4.3	4.6	12.8	23.5	34.8	19.9	23.0	23.8	0.0	0.1	1.9	0.8	0.3	0.4
	Marlen	yes	3.7	2.4	3.2	4.1	3.9	4.8	18.8	30.4	33.9	22.6	24.2	25.0	0.1	1.0	1.2	0.6	0.8	0.8
		no	6.3	3.2	3.2	6.4	7.2	6.6	14.6	28.2	32.6	20.2	20.6	20.3	0.0	0.2	1.1	0.5	0.2	0.5
Winter wheat	Agria	yes	4.2	2.8	2.3	3.5	3.1	3.6	16.0	25.6	30.4	25.8	25.4	25.9	0.2	0.6	2.5	0.9	1.2	0.9
		no	8.5	4.7	4.5	5.4	4.1	4.5	10.8	23.6	31.0	20.9	23.0	24.3	0.0	0.3	0.4	0.1	0.3	0.5
	Marlen	yes	4.3	2.8	3.0	4.1	3.6	4.6	18.4	27.3	29.2	20.4	24.1	26.2	0.0	0.2	0.5	0.5	1.1	1.1
		no	5.3	3.5	4.0	6.3	6.0	6.1	15.2	24.0	29.2	17.3	19.2	21.4	0.0	0.1	0.1	0.8	0.6	1.1
S.E.D.[1]/d.f.		PC	0.63/126			1.32/86.6			1.61/114			1.64/100			0.73/83.7			0.46/107		
		HAR•TIME	0.63/98.8			1.16/74.3			1.58/71.9			1.57/85.4			0.68/71.8			0.44/79.8		
		CV/PS	0.63/89.9			1.20/77.1			1.50/83.2			1.48/88.3			0.73/60.5			0.43/84.1		

[1] The standard errors of a difference are relevant for comparison of means of, e.g. preceding crops (PC) at a given combination of the factors cultivar (CV), pre-sprouting (PS) and harvest time (HAR•TIME). Denominator degrees of freedom were approximated by the Kenward-Roger method and may vary among years and traits.

Table 3.9: The effect of preceding crop (PC), cultivar (CV) and presprouting (PS) and harvest time (HAR•TIME) on graded tuber yield (t ha^{-1}) relevant for French fry production at subsequent harvests in 2003 and 2004

			(a) % of tuber yield > 35 mm in total FM yield						(b) % of tuber yield 35-50 mm in total FM yield						(c) % of tuber yield > 50 mm in FM yield (> 35 mm)					
			2003			2004			2003			2004			2003			2004		
PC	CV	PS	15-	28-07	17-09	28-07	13-08	09-09	15-07	28-07	17-09	28-07	13-08	09-09	15-07	28-07	17-09	28-07	13-08	09-09
Peas	Agria	yes	4.6	2.1	2.3	4.1	2.0	3.7	53.1	31.8	24.5	52.6	45.6	50.9	44.3	67.4	74.8	45.1	53.4	47.1
		no	15.0	5.7	3.8	6.0	5.0	4.6	75.5	61.3	36.0	64.7	63.3	56.1	11.1	34.9	62.6	31.2	33.4	41.0
	Marlen	yes	5.2	2.7	2.4	4.8	4.5	4.3	64.6	45.6	36.4	47.0	47.8	47.4	31.8	53.1	62.7	50.6	49.9	50.4
		no	6.8	3.2	2.9	8.5	5.0	6.6	75.9	51.3	44.8	59.0	53.6	54.4	18.5	46.9	53.8	35.3	43.4	41.5
Oats	Agria	yes	5.7	3.7	2.4	4.3	4.0	3.9	59.2	43.0	31.1	55.2	55.1	52.2	37.3	55.2	68.2	42.2	42.6	45.6
		no	16.2	7.1	4.2	5.4	4.5	5.2	74.4	67.1	50.6	74.2	67.0	67.5	11.4	27.7	47.1	21.6	29.8	28.8
	Marlen	yes	5.8	2.7	2.5	7.9	5.9	5.9	62.3	49.4	43.6	52.4	43.4	53.5	33.9	49.2	55.3	43.2	53.8	43.1
		no	8.0	3.4	2.3	9.7	6.4	9.7	79.6	58.3	47.3	65.1	61.8	65.4	13.4	39.7	51.6	27.7	33.9	27.5
Alfalfa-grass-clover	Agria	yes	6.2	3.8	2.3	4.2	3.2	3.4	57.3	38.0	26.8	51.7	40.9	46.5	38.9	60.5	72.6	45.9	57.8	51.8
		no	14.8	6.1	3.6	8.3	5.0	4.4	70.9	60.6	38.5	67.1	64.2	67.0	16.3	35.4	60.1	26.6	32.5	29.8
	Marlen	yes	4.9	2.3	3.2	5.7	5.5	6.0	66.1	41.7	38.7	51.3	49.8	56.8	30.4	57.3	59.9	45.6	47.2	39.4
		no	10.4	3.3	3.0	9.3	8.9	8.4	79.4	55.8	42.2	60.0	68.4	67.6	11.2	42.2	56.5	33.8	24.9	26.2
Winter wheat	Agria	yes	7.9	3.4	2.7	3.8	3.6	3.5	64.0	47.3	32.6	57.0	52.9	55.6	30.4	51.0	66.4	40.7	45.1	42.3
		no	16.3	5.9	4.7	7.0	4.8	4.7	74.2	64.1	51.7	70.0	67.3	66.9	11.3	31.9	45.8	24.7	29.3	29.7
	Marlen	yes	6.2	2.8	2.7	5.7	4.8	4.9	71.1	49.0	45.3	54.0	47.7	52.3	24.1	49.6	53.4	42.7	49.9	45.0
		no	7.7	3.9	4.4	10.0	8.4	7.9	79.0	62.6	56.0	64.0	64.4	61.8	14.4	34.9	41.4	28.8	29.6	32.8
S.E.D.[1]/d.f.		PC	1.27/132			1.13/138			4.27/117			4.86/141			4.74/120			5.44/141		
		HAR•TIME	1.29/99.3			1.13/135			4.22/101			4.86/141			4.66/102			5.44/141		
		CV/PS	1.29/100			1.12/124			4.29/82.2			4.86/141			4.76/82.7			5.44/141		

[1] The standard errors of a difference are relevant for comparison of means of, e.g. preceding crops at a given combination of the factors cultivar (CV), pre-sprouting (PS) and harvest time (HAR•TIME). Denominator degrees of freedom were approximated by the Kenward-Roger method and may vary among years and traits.

Table 3.10: The effect of preceding crop (PC), cultivar (CV) presprouting (PS) and harvest time (HAR•TIME) on (a) number of tubers m^{-2} and (b) average tuber weight (g) at subsequent harvests in 2003 and 2004

			(a) Tubers m^{-2}						(b) Average tuber weight (g)					
			2003			2004			2003			2004		
PC	CV	PS	15-07	28-07	17-09	28-07	13-08	09-09	15-07	28-07	17-09	28-07	13-08	09-09
Peas	Agria	yes	35.7	33.6	38.9	37.1	34.1	33.5	68.6	100.6	118.0	91.6	103.6	93.4
		no	49.0	42.7	39.5	35.7	36.9	32.0	42.0	66.1	107.8	81.3	79.9	89.8
	Marlen	yes	42.0	45.5	40.4	39.9	40.4	39.1	62.9	82.2	99.1	82.1	81.7	83.9
		no	46.5	47.5	37.6	40.5	34.9	41.8	50.2	70.9	102.2	69.8	85.2	74.1
Oats	Agria	yes	33.2	36.8	43.4	31.3	37.9	30.0	67.5	87.0	85.7	85.6	76.0	91.1
		no	44.5	44.5	40.5	32.1	34.6	31.5	41.6	63.5	94.0	76.1	77.2	80.9
	Marlen	yes	38.0	38.1	40.9	38.6	35.0	36.6	63.3	75.8	83.5	68.6	82.2	75.9
		no	42.0	43.1	39.8	40.7	36.5	38.0	50.8	70.5	81.9	57.5	72.2	60.6
Alfalfa-grass-clover	Agria	yes	34.3	35.5	41.3	32.6	35.9	34.9	67.3	89.0	102.5	91.7	86.5	90.0
		no	41.7	42.2	43.3	36.6	36.6	34.1	48.6	66.7	92.4	73.0	77.9	84.6
	Marlen	yes	36.1	37.4	39.9	36.0	38.3	41.3	62.9	90.3	96.0	76.4	77.5	74.3
		no	43.3	44.4	38.0	44.2	41.5	41.5	48.3	71.3	98.0	61.7	71.5	66.1
Winter wheat	Agria	yes	33.6	34.3	40.4	35.3	38.0	34.5	61.2	85.3	88.1	86.2	79.2	88.8
		no	42.2	42.3	39.3	35.4	38.3	34.4	45.7	67.6	91.7	74.6	72.1	85.5
	Marlen	yes	38.4	38.2	37.8	33.0	39.7	40.1	59.2	79.6	87.2	75.5	73.7	79.7
		no	39.3	41.9	43.6	39.5	39.9	44.1	52.7	66.1	76.8	61.9	64.4	65.2
S.E.D[1]/d.f.		PC		2.61/104			3.03/92.9			3.03/92.9			3.03/92.9	
		HAR•TIME		2.49/78.0			3.95/83.5			3.95/83.5			3.95/83.5	
		CV/PS		2.43/76.4			2.71/87.4			2.71/87.4			2.71/87.4	

[1] The standard errors of a difference are relevant for comparison of means of, e.g. preceding crops at a given combination of the factors cultivar (CV), presprouting (PS) and harvest time (HAR•TIME). Denominator degrees of freedom were approximated by the Kenward-Roger method and may vary among years and traits.

3.4 Discussion

Next to nitrogen, potassium is the element most limiting potato tuber yield. Yield response to an increased N supply depends to a great extent on the level of K nutrition, the interaction usually being positive (Herlihy and Carroll 1969). A soil content of 40-100 g K kg^{-1} in topsoil, however, is commonly considered to be adequate for potato tuber yields in organic cropping systems where N supply is usually limited (Pang and Letey 2000). At potato crop emergence, available K_{CAL} in soil ranged from 77 (2004) to 98 g K kg^{-1} (2003), hence K was probably not a growth limiting factor in the present experiments.

3.4.1 Nitrate-N availability

The comparatively higher NO_3-N content of soil under AGC in winter 2002-2003 (Fig. 3.2a) was probably caused by the relatively high temperatures during November (Table 3.1) when N from decaying leaves and roots of the legume/grass ley may have been mineralized (Jarvis et al. 1997). The very low level of nitrate-N under the catch crop at the November sampling indicates that most of the excessive mineralized N had been taken up. The significant – even though in absolute numbers small – increase of mineralized NO_3-N after peas at the November 2003 (Fig.3.2b) sampling suggests a high N potential of this crop as compared to cereals. The substantially higher N uptake by the catch crop after peas in both years (Table 3.2) supports this strongly.

The observed appreciable increase of mineralized nitrate-N up to crop emergence has been described by others for both conventional and organic potato cropping systems (Wheatley and Ritz 1995, Walther et al. 1996, Stein-Bachinger and Werner 1997). In the present study it may be traced back upon the increasing air temperature in early spring (Table 3.1), but also ploughing in late winter and seedbed preparation in April (Table 3.2) both causing aeration and thereby promoting N mineralisation by micro-organisms (Jarvis et al. 1996). The appreciably lower NO_3-N concentration in 2004 at crop emergence may possibly be explained by the lower average daily temperature in May 2004 (11.5 °C) compared with 2003 (14.1 °C).

In the present study the NO_3-N contents measured at 0-60 cm at the end of May were very high in one year after both peas and the legume/grass ley (on average > 175 kg NO_3-N ha^{-1} in 2003). Apart from this, even after cereals, soil NO_3-N in both years ranged fairly high (90-130 kg ha^{-1}), which probably can be attributed to the high soil fertility at Frankenhausen (Jörgensen et al. 2002). In 2003, the high potential of a short-term legume grass ley to increase N supply to potato crops became evident, the difference between highest (AGC) and lowest (WW) availability amounting to > 80 kg NO_3-N ha^{-1}. Other researchers reported an increased availability of mineralized N in organic potato cropping after 2-year grass-clover leys compared to cereal grains (Stein-Bachinger and Werner 1997). Further research should consider comparisons between 2- and 1-year (both autumn- and spring-sown) grass-clover leys. The sensitivity of a short-term ley to the environmental conditions in the preceding crop season seems to be substantial. Low water supply limits N-fixation of the legume component in a grass-clover mixture (Søgaard 1990) and was probably the reason for poor and comparatively low N supply from AGC in 2004. Over both experimental seasons, peas (with a subsequent catch crop) most reliably supplied very high amounts of mineralized N to the potato crop. The results of Reiter et al. (2002) who measured a negative net N balance of field-grown peas indicated that this was not necessarily to be expected. The observed subsequent decline in available N followed the dynamics of mineralized N under potatoes described by others (Wheatley and Ritz 1995, Walther et al. 1996). The former differentiation between preceding crops was levelled out as the growing season proceeded. A rise in soil NO_3-N after harvest of organic potato crops has been observed by Zihlmann et al. (2000). This could not be established in the present experiments, probably due to the rather early sampling just before final harvest. Yet, the slightly increased nitrate-N after alfalfa/grass-clover in 2003 (Fig. 3.2a) indicates an onset of late mineralization of legume/grass residues which confirms the high potential of this preceding crop for NO_3-N leaching observed by Neeteson (1989).

3.4.2 Pre-sprouting and early crop development

Initially, the potato crop has limited N uptake for a period of 40 days or more after planting (Millard 1986). Hence, the impact of an increased N supply at emergence on above-ground phenological crop growth stages may be regarded to be very small. According to the present study, the response of crop development to seed-tuber preparation by pre-sprouting is much more substantial. The observed shortening of pre-emergence development has also been reported by other researchers in the past (Reust et al. 1982, Moll 1985). Probably due to the cool weather conditions in May (Table 3.1), early crop development of all treatments proceeded much more slowly in 2004 (Fig. 3b). Results confirmed that cultivars with a very profound dormancy such as cv. Agria (Bundessortenamt 2003) benefit more from pre-sprouting in terms of early crop development (Karalus and Rauber 1997).

3.4.3 Crop DM accumulation and translocation

The study also showed that an increased N supply increases DM accumulation in leaves and stems. Canopy DM at the end of July reflected the differentiated N supply at crop emergence very well, except for the legume-grass ley in 2003, which obviously released additional N during the main growing period at a later stage. In 2004 when conditions for early crop growth were unfavourable, cv. Marlen responded to the relatively low N supply after cereals with an appreciably lower canopy DM than cv. Agria. Statistical analysis (Table 3.3) gave evidence that the interaction of preceding crop and cultivar may have a marked effect upon crop growth expressed as tuber and total crop DM accumulation. The lower canopy DM of crops when seed-tubers had been pre-sprouted can probably be explained by the advanced translocation of assimilates into tubers, which is supported by the lower canopy/tuber DM ratio of pre-sprouted crops (Table 3.5). In fact, at the end of July, pre-sprouting consistently caused higher tuber DM yield. This indicates that pre-sprouting may have a favourable impact upon suitability of tubers for processing, since high tuber DM content is a pre-requisite for processing. Moreover, results confirmed that pre-sprouting promotes tuber DM accumulation particularly in growing seasons when unfavourable conditions for crop growth prevail (Toosey 1964, Karalus and Rauber 1997). The higher canopy DM/tuber DM ratio of cv. Agria was due to both its higher canopy and lower tuber DM. Overall, results show that the preparation of seed tubers promotes a favourable crop development with regard to early translocation of assimilates.

3.4.4 Crop N uptake and translocation

The initial phase of slow N uptake is followed by a period of very rapid N uptake, which is then followed by a period when it is limited and translocation from canopy occurs in response to tuber bulking. Translocation is an important physiological process for the maintenance of tuber growth when N uptake from soil decreases (Dyson and Watson 1971; Millard and Marshall 1986). By the time of canopy sampling (end of July), nitrate-N in soil was already at a very low level in both years. The higher N uptake by the canopy after leguminous preceding crops in 2003 and the lower N uptake after oats in 2004 (Table 3.4) reflected the N status of the soil around crop emergence (Fig. 3.2) very well. It could be shown that canopy N uptake after leguminous crops is usually higher than after cereals which was in accordance with Honeycutt et al. (1996). The lower total N of the canopy and higher N uptake by tubers after pre-sprouting (Table 3.5) suggests that translocation of N from canopy into tubers had been advanced by seed tuber preparation. The considerably lower N uptake of tubers grown after oats at final harvest 2004 confirms Millard and MacKerron (1986) who stated that potato crops with limited N supply can translocate only relatively small amounts of N from canopy to tubers.

The low N utilization efficiency after alfalfa-grass/clover (Table 3.6) implies that N taken up by the whole crop was only insufficiently transformed into final tuber yield. The fact that cereals displayed higher N utilization efficiency in 2003 shows that potato crops did not use the full potential of the increased N supply after legumes, probably due to very dry conditions in the summer of 2003. Even though, in 2004, preceding crops caused a differentiated total crop N uptake, N utilization efficiency was not affected ($P = 0.05$; Table 3.3), probably as a result of the late blight epidemic assessed in July and August 2004. In that year, an increased N utilization efficiency was only achieved by pre-sprouting (Table 3b), confirming the importance of this agronomic measure in seasons distinguished by late blight. Moreover, regression analysis gave evidence that tuber DM and FM yield is highly related with total dry matter of potato crops (Allen and Scott 1980).

3.4.5 Tuber yield formation: Total and size-graded yields

As shown in this paper, the individual season (temperature, precipitation) under conditions of organic farming has a marked effect upon growth and the N supply (preceding crop) at crop emergence, as well as the uptake and use of available N for tuber yield formation. Moreover, development of tuber yield is also very much dependent upon the year, and it can be confirmed that late blight can be a decisive factor (Finckh et al. 2006), as, in 2004, final tuber yield was accomplished as early as mid-August. Cultivar choice then played an important role, and cv. Marlen could compensate its genetically determined lower yield potential through earlier tuber yield formation.

Möller and Kolbe (2003) regarded 130 kg NO_3-N ha^{-1} in 0-60 cm at crop emergence a high N supply, allowing final tuber yields of 30-40 t FM ha^{-1}. In 2004, this threshold for N availability was reached only after peas, but final yield after that preceding crop hardly exceeded 30 t FM ha^{-1}, which again was probably a consequence of late blight. Hence, it may be concluded that final FM tuber yield in a season where this fungal disease is prevalent benefits much more from pre-sprouting than a high N supply provided by leguminous preceding crops (Toosey 1964, Karalus and Rauber 1997). Further research, however should comprise control plots with chemical control of late blight.

At a given total FM tuber yield, yield in the size grade 40-65 mm should be as high as possible to make cultivation of potatoes for processing into crisps more profitable. According to this study, tuber yield < 40 mm can mainly be reduced by pre-sprouting seed-tubers, and by cultivar choice. In contrast, an increasing N supply (after peas) may be efficient in terms of higher yields of the medium (marketable) size grades (40-65 mm), but may raise oversized tuber yields in seasons when crop growth is undisturbed by *P. infestans*. As any available means consistent with the standards of organic farming has to be used by the farmer to increase marketable yield, choice of a cultivar with a genetically determined medium number of tubers may prevent economic losses due to high portions of oversized tubers.

In comparison, the role of the crop preceding potatoes is more important for a profitable cultivation of tubers for processing into French fries. Leguminous preceding crops like peas not only reduce the portion of undersized (< 35 mm) tubers, but increase the percentage of the preferred tuber size grade (> 50 mm) within marketable tuber yield (> 35 mm). At the end of July, foliage of organic potato crops in Western and Central Europe is often devastated by late blight. In such a season, organic crops would probably not yield the required portion tuber yield > 50 mm, i.e. the farmer would have to select part of the medium tubers (35-50 mm) in order to make raw material marketable. Pre-sprouting proved to be the most efficient means to minimise such losses.

3.4.6 Tuber yield components

A high tuber density of a cultivar is usually compensated by lower average tuber weight (Hunnius 1977), and this may hold true especially for conditions of organic faming where N supply is generally limited. In 2003, the pre-sprouted seed-tubers initiated less progeny tubers of higher mean tuber fresh weight up to the end of July, but crops not pre-sprouted compensated for this in most cases up to harvest at maturity. Hence, it cannot be concluded from the results, whether the response of tuber density in organic potato cropping is rather determined by pre-sprouting (2003) or cultivar (2004), but obviously no effect of preceding crop should be expected. In 2004, the beneficial effect of pre-sprouting on final mean tuber fresh weight was still detectable in September. Overall, tuber density was only inconsistently affected by seed-tuber preparation, whereas average tuber fresh weight responded very clearly and positively to seed-tuber preparation (pre-sprouting), cultivar (cv. Agria) and an increased N supply (after peas).

3.4.7 Mixed models for complex field experiments

Many experiments conducted by plant scientists employ an experimental design, which is not found in standard textbooks, because the research question is rather complex and common designs do not fully meet the need of the experimenter. It may be useful in such situations to involve a statistician at the design stage. Provided that the design is properly randomized, a valid statistical analysis can be furnished even for rather complex settings. Typically, the experiment will comprise several randomization steps, and thus involve multiple error strata, which need to be accounted for in the analysis. This paper shows, how the approach outlined in Piepho et al. (2003, 2004) can be used to formulate a suitable mixed model for the design at hand. Essentially, each randomization unit (main plot, sub plot, row or column) receives a separate random effect. In addition, crossing of randomization steps generates additional random effects reflecting the field design. The procedures given in Piepho et al. (2003, 2004) are designed to make sure that no random effect is missed.

Often, random effects for randomization units are coded by crossing suitable treatment and block effects, and this route was taken in the present paper. It is stressed, however, that it is not always obvious, which treatment factor should be used to define random effects for experimental units. This is typically the case, when a complex treatment structure is involved that is not aligned, in a simple way, with randomization structure. It is therefore generally good policy to keep the treatment model entirely separate from the block model, i.e., the model for experimental units (replicates, blocks, plots, etc.). This necessitates that each type of experimental unit be uniquely identified by a separate block factor. The block model can then be formulated using only the block factors, but not the treatment factors (Piepho et al. 2003), thus greatly facilitating the assembly of a suitable full model.

Repeated measurements require special attention at the analysis stage due to serial correlation. The common practice of analysing repeated measurements as if they were independent is clearly inappropriate, yielding invalid inferences (Schabenberger and Pierce 2002). In this paper, repeated measures were therefore analysed fitting a serial correlation structure. There are usually several correlation structures among which a choice needs to be made, so analysis is a little more involved than the analysis of independent data. The most common approach is to fit the candidate correlation structures by Restricted Maximum Likelihood (REML) and then to select the best-fitting model by a likelihood-based criterion such as Akaike Information Criterion (AIC). When models are nested, a likelihood ratio test is possible, and this was exploited in the present paper to compare the independent model to an AR(1) model.

3.5 Conclusion

Overall, the experiments showed that organic potato crops do not necessarily have to suffer from N stress, e.g. when leguminous precrops such as field peas predede potatoes in crop rotation. Even though an increased N supply may alleviate N stress common in many organic potato crops, and lead to higher canopy dry matter and N uptake, it does not guarantee significantly increased tuber yield. Results gave evidence that crop development and tuber yield formation of cultivars respond differently to a differentiated N supply which, again, may affect N utilization efficiency. As a consequence, choice of an adequate cultivar and pre-sprouting may lower the risk of high portions of tuber size-grades that are not marketable.

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4 Suitability of organic potatoes for industrial processing: Effect of agronomical measures on selected quality parameters at harvest and after storage

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Abstract

Three factorial field experiments were conducted in two consecutive years (2003-2004) on two sites in order to examine the impact of preceding crop, pre-sprouting, N- and K- fertilization, and cultivar on quality attributes of potatoes destined for processing into French fries or crisps. Tuber dry matter (DM) concentration, glucose and fructose concentration, as well as the colour of crisps and the quality of French fries were assessed, at harvest and after storage.

Results suggest that tubers from organic potato cropping may be expected to have sufficiently high tuber DM (>19%) for processing into French fries, without impairing texture of fries, when the concentration exceeds 23%. DM concentration of tubers for crisps (cv. Marlen) fell short of the required minimum of 22% when the combined N and K fertilizer was applied. DM was significantly lower following peas instead of a legume-grass/clover ley or cereal grains (oats or winter wheat), but only in one of two seasons. Pre-sprouting increased tuber DM concentration considerably, especially in the growing season with a high incidence of *Phytophthora infestans* (+1.2% absolute increase). Tuber DM concentration was significantly higher after storage in two of three experiments (+0.4 and 0.5% absolute increase).

Cultivars belonging to the very early and early maturity type showed the largest relative increase of reducing sugars due to storage, ranging between 300 and 1100%. The medium-early cv. Agria and medium-late cv. Marena proved to be best suited for processing into French fries under conditions of organic farming, as only minor deviations from highest quality standards were established at harvest (quality index at 4.3 and 4.1, respectively). Consistently high crisp quality was reached by medium-early cv. Marlen (L-value of 70.8 and 66.7 at harvest and after storage, respectively).

Overall, results show that variability of dependent variables was mainly affected by cultivar, season, storage and their interaction. Hence, the effect of agronomic measures such as fertilization, preceding crop and seed-tuber preparation may be rather small and the response of internal tuber quality and quality of fried products be hardly predictablevery difficult to predict. The quality standards for tuber raw stock can be accomplished best when adequate cultivars are chosen.

Crisps; cultivar; dry matter concentration; French fries; K-supply; N-supply; preceding crop; pre-sprouting; reducing sugars

Abbreviations

CC	catch crop
CV	cultivar
FERT	fertilization
FW	fresh weight
DM	dry matter
OF	organic farming
PC	preceding crop
PRS	pre-sprouting
REP	replication (block)
STOR	time of assessment

4.1 Introduction

The potato crop plays an important agronomic and economic role for the majority of organic farms in Western Europe. Organic cultivation of potato raw stock for industrial processing of French fries or crisps may be a new source of income for organic farmers (Kuhnert et al. 2004), yet research until recently exclusively focused on table potatoes (Thybo et al. 2001; Neuhoff and Köpke 2002; Wszelaki et al. 2005). The quality standards for processing potatoes differ markedly from those for table potatoes. There are ranges and thresholds for the DM concentration of tubers, as well as for the concentration of reducing sugars within tuber fresh matter. According to Schuhmann (1999), tuber DM concentration should range between 19 and 23% for French fries and exceed 22% for crisps. Tuber reducing sugar concentration of conventional and organic raw stock should not be greater than 1.5 for crisps and 2.5 g kg^{-1} fresh weight for French fries, respectively. Furthermore, tubers should not only meet these standards shortly after harvest, but also after storage, which is known to have an appreciable impact on reducing sugar accumulation (Kumar et al. 2004).

Likewise, conventional potato cultivation, the main factor limiting yield in organic potato cropping is nitrogen (N) (Vos 1995; Finckh et al. 2006). Reports on the effect of N on reducing sugar (glucose and fructose) concentrations and consequently the quality (colour) of the finished, fried product are conflicting (Iritani and Weller 1978; Hughes et al. 1986; Roe et al. 1990; Westermann et al. 1994b). Kumar et al. (2004) concluded that plants adequately fertilized with N have lower reducing sugar concentrations.

N nutrition in organic potato cropping can be accomplished by either cultivating potatoes following preceding crops providing relatively high amounts of N, such as legumes (Stein-Bachinger and Werner 1997; Finckh et al. 2006; Haase et al. 2007b), or by application of organic N sources (Haase et al. 2007a) as long as they are in accordance with EU regulation 2092/91. However, very high soil N or N released too early may promote excessive canopy growth and increase the proportion of immature tubers (Ojala et al. 1990; Roberts et al. 1982), and this negative effect on processing quality may be aggravated by early incidence of *Phytophthora infestans* (Möller 2002). It is suggested that pre-sprouting of seed-tubers may have an impact on maturation of tubers by accelerating crop development at early growth stages (Karalus and Rauber 1997). Hence, one aim of the present study was to examine potential interactions of N supply by different preceding crops and seed-tuber-pre-sprouting and their impact on internal processing attributes (dry matter, reducing sugars) and quality of the finished product (French fries, crisps) under conditions of organic farming (Experiment 1).

Potassium (K) nutrition of potato crops may also have an effect on processing attributes, such as DM concentration (Rogozińska and Pińska 1991; Westermann et al. 1994a; Allison et al. 2001) and reducing sugar concentration. Stanley and Jewell (1989) observed no significant relation between reducing sugars and rate of K. Others observed that increasing applications of K decreased reducing sugar concentrations and lightened crisp colour (Wilcox 1961; Murphy and Goven 1966; Herlihy and Carroll 1969; Sharma and Arora 1988; Chapman et al. 1992). In organic crop rotations, K-rich organic fertilizer such as cattle manure is very limited. Stockless organic farms may be inclined to fall back on mineral sources of K if organic manure is not available. Another goal of this study was to find out whether sufficient processing quality of tuber raw stock can be secured by application of cattle manure instead of mineral K fertilizers. Previous research has usually concentrated on the response of crops to K fertilizer in the presence of adequate/high levels of available N. Hence, we investigated the effect of K application when supplemental N (horn grits) was added (Experiment 2).

Putz and Lindhauer (1994) stated that cultivar had a more pronounced effect on reducing sugar concentration than, *e.g.*, aspects of crop nutrition. Therefore, we also tried to quantify the impact of cultivar choice on internal tuber quality as well as French fry and crisp colour (Experiment 3).

In three field experiments conducted in the two consecutive seasons 2003 and 2004, the impact of preceding crop, seed tuber-pre-sprouting, N- and K-fertilization, and cultivar on tuber DM, reducing sugar concentrations, and quality profile of the finished product (French fries and crisps, respectively) was examined twice, at harvest and after a storage period of 4 months at 8 °C. Effects of these factors on tuber yields were reported in two earlier papers (Haase et al. 2007a,b).

4.2 Material and methods

4.2.1 Field experiments

Three field experiments were conducted in two successive years, 2003 and 2004, at two locations in Central and Northwestern Germany (Table 4.1).

Field experiment 1 was set up on an organic farm near Osnabrück, Germany (52° 2'N, 8° 8'E) in a split-plot design with fertilization as main plot factor and cultivar as sub-plot factor (Table 4.2). Soil type was a Haplic Luvisol, soil texture was loamy sand, annual precipitation amounted to 856 mm, mean annual temperature was 9.1 °C (1960-1990) (Anonymous 2005). Precipitation from March to August in 2004 (432 mm) was consistent with the 30-year average (426 mm), but only 285 mm were recorded in 2003. A higher total precipitation was recorded in July 2004 (114 mm), compared to 2003 (80 mm). A pronounced deviation from the long-term monthly average daily temperature was measured from June to August in 2003 (Table 4.3). Preceding crops were one-year grass/clover (mulched; *Lolium perenne* L. and *Trifolium pratense* L.) in 2003 and winter wheat (*Triticum aestivum* L.) in 2004. Fertilizers applied (in spring) were deep litter cattle manure from suckler cows, potassium sulphate (40% K), potassium sulphate + horn grits, horn grits (14% N), and a control with no fertilizer application at all (Table 4.2). Cattle manure served as a reference fertilizer for K and N, i.e. the respective amounts of K (195 kg ha^{-1}) and N (137 kg ha^{-1}) were applied with potassium sulphate (K), horn grits (N) and potassium sulphate + horn grits (K + N). Fertilizers were incorporated on 11 April 2003 and 14 April 2004, just after application (Haase et al., 2007b).

Field experiments 2 and 3 were conducted at the Research Farm of the University of Kassel (51°4' N; 9°4' E), Germany, the Hessische Staatsdomäne Frankenhausen, located 230 meters above sea level (Table 4.1). The farm had been converted to organic farming (OF) between 1999 and 2001 and is a certified member of two OF associations (Naturland and Bioland). Soil type of both experimental fields was a Haplic Luvisol, soil texture a silt loam.

In 2003, precipitation was extraordinarily low from March through September, except in June, when rainfall exceeded the long-term average by 20 mm. In contrast, rainfall in 2004 was in accordance with the long-term mean. However, exceptionally high precipitation was measured in July (135 mm), compared to the 30-year mean (65 mm). A pronounced deviation from the long-term average daily temperature was measured from June through August in 2003, while in May 2004 it was very low

(Table 4.3). Late blight (*P. infestans*) was assessed weekly as percent diseased leaf area, following the scheme given by James (1971).
Start of field experiment 2 was in the season 2001/2002. On both fields, the pre-pre-crop was spring barley (*Hordeum vulgare* L. cv. Theresa). In the pre-test season, four different preceding crops (PC) were cultivated in strips: winter wheat (*Triticum aestivum* L. cv. Bussard); oats (*Avena sativa* L. cv. Jumbo), peas (*Pisum sativum* L. cv. Classic) and an alfalfa-grass/clover ley (*Medicago sativa* L., *Trifolium repens* L., *T. pratense* L., *Lolium perenne* L., *Festuca pratensis* Huds.) (Table 4.2). The ley was cut and removed twice. Harvest of cereals and peas was immediately followed by soil tillage and a catch crop mixture of *Raphanus sativus* L. (cv. Siletta) and *Phacelia tanacetifolia* BENTH (cv. Vetrovska) sown at a ratio of 24 : 6 kg/ha. Both catch crop and the alfalfa-grass/clover ley were ploughed under at frosty weather on 31 and 28 January, 2003 and 2004, respectively. In 2003, the four subplot factor combinations of cultivar (Agria and Marlen) and pre-sprouting (yes and no) were assigned in two single randomization steps. In 2004, cultivar was randomly assigned to subplots and subsequently pre-sprouting was assigned to sub-sub-plots.

The two cultivars used in Exps 1 and 2 are regarded as being suitable for processing into French fries (Agria) and crisps (Agria, Marlen) (Böhm et al. 2002).

In experiment 3, 10 cultivars from different maturity groups and suitable for both French fries and crisps (Böhm et al. 2002) were cultivated as a one-factorial randomized complete block design in four replications. Preceding crops in both seasons were winter cereals (*Secale cereale* L. and *Triticum aestivum* L., respectively).

Seed tubers for experiments were graded 40-50 mm and pre-sprouted, keeping two to three tuber layers in white boxes (600 × 400 × 190 mm; Bekuplast, Ringe, Germany) illuminated at 20 °C for 3 days and at 10–15 °C for the following 5–6 weeks. By contrast, unsprouted seed (Experiment 1) was stored in a dark, cool place (8-10 °C; 85% RH) until three days before planting. Seed tubers were planted with a two-row planter at 34 cm with rows 75 cm apart, at a depth of 8–10 cm. Weeds were controlled by harrowing and hilling and manual weeding. Colorado beetle (*Leptinotarsa decemlineata*) was controlled using *Bacillus thuringiensis* (Novodor FC®, Agrinova, Neudorf, Germany) in 2003 and neem extract (Neem Azal®-T/S, Trifolio-M GmbH, Lahnau, Germany) in 2004 according to application guidelines. The potato crops were lifted with a one-row harvester and picked up by hand. After two weeks for wound healing, subsamples of tubers were subjected to assessment of quality parameters. All agronomical measures (e.g. crop protection and fertilization) carried out in field trials were in accordance with the EU regulations for organic farming. Further details on experimental design, sites and weather conditions are presented in Tables 4.1 – 4.3 and Haase et al. (2007a,b).

Table 4.1: Soil and agronomical parameters of the experimental locations

	Exp. 1		Exp. 2		Exp. 3	
	2003	2004	2003	2004	2003	2004
Date of soil sampling	11 April	7 April	11 April	17 April	22 April	18 April
pH (CaCl$_2$)	5.6 ± 0.02 [b]	5.7 ± 0.13	6.6 ± 0.04	6.8 ± 0.02	7.3 ± 0.12	6.8 ± 0.04
P (CAL) (mg kg^{-1}) in 0-30 cm	53 ± 2.1	42 ± 0.8	69 ± 1.2	58 ± 0.8	77 ± 6.0	65 ± 7.9
K (CAL) (mg kg^{-1}) in 0-30 cm	126 ± 2.3	76 ± 2.4	98 (89 -102) [a]	77 ± 2.2	149 ± 8.7	59 ± 7.7
Mg (CaCl$_2$) (mg kg^{-1}) in 0-30 cm	54 ± 7.4	35 ± 3.5	80 ± 1.2	69 ± 0.4	84 ± 4.9	88 ± 6.6
NO$_3$-N (kg ha^{-1}) in 0-60 cm	59 ± 3.6	12 ± 1.9	66 (38 - 84) [a]	67 (43 - 75) [a]	37 ± 2.3	48 ± 2.7
Preceding crop	Grass clover [c]	Winter wheat [d]	Spring barley e[5]		Winter rye	Winter wheat
Date of planting seed tubers	20 April	27 April	25 April	22 April	15 April	16 April

[a] Where statistical analysis gave significant treatment effects, ranges (min and max) are given in brackets

[b] means ± standard deviation

[c] Grass clover undersown in cereals in 2001, and mulched 3 x in 2002

[d] Plus a catch crop (*Trifolium incarnatum* and *Raphanus sativus* L.) undersown in wheat

[e] Pre-pre-crop (pre-crops see Table 4.2)

Table 4.2: Factors and factor levels in Exps 1, 2 and 3 in the seasons 2003 and 2004. Storage (STOR) and year (YEAR) were additional factors in the experiments

	Factor 1	Factor 2	Factor 3
Exp. 1	Fertilization (FERT)	Cultivar (CV)	
	1) Cattle manure	1) Agria	
	2) Potassium sulphate	2) Marlen	
	3) Potassium sulphate + horn grits (HG)		
	4) Horn grits		
	5) No fertilization (control)		
Exp. 2	Preceding crop (PC)	Cultivar (CV)	Pre-sprouting (PRS)
	1) Peas	1) Agria	1) Yes
	2) Alfalfa-grass/clover	2) Marlen	2) No
	3) Oats		
	4) Winter wheat		
Exp. 3	Cultivar (CV) and maturity type	Processed into	
	1) Premiere (very early)	French fries	
	2) Velox (very early)	French fries	
	3) Camilla (early)	French fries	
	4) Carmona (early)	French fries and crisps	
	5) Delikat (early)	Crisps	
	6) Agria (medium early)	French fries and crisps	
	7) Freya (medium early)	French fries	
	8) Marlen (medium early)	Crisps	
	9) Marena (late)	French fries	
	10) Saturna (late)	Crisps	

Table 4.3: Rainfall and average daily temperature at the experimental site during 2003-2004 (Anonymous 2005)

	a) Exp. 1						b) Exps 2 and 3					
			Departure from long-term mean						Departure from long-term mean			
	Long-term mean (1960-1990)		2003		2004		Long-term mean (1960-1990)		2003		2004	
	Rainfall (mm/month)	Average daily temperature (°C)	mm/month	°C	mm/month	°C	(mm/month)	(°C)	mm/month	°C	mm/month	°C
Jan	78	1.2	24	0.2	9	0.9	55	0.2	14	0.0	44	0.4
Feb	55	1.7	-28	-1.6	13	2.0	43	1.2	-27	-2.7	19	1.7
Mar	69	4.5	-40	2.4	-23	0.7	51	4.4	-20	1.8	-13	0.1
Apr	57	8.0	3	1.3	-14	2.1	50	8.3	-27	0.6	-3	1.4
May	68	12.6	-5	1.1	-16	-0.6	67	12.9	-30	1.2	-23	-1.4
Jun	86	15.7	-65	2.8	-17	-0.3	79	16.0	19	3.2	-23	-0.7
Jul	74	17.1	6	1.9	40	-0.5	64	17.5	-13	1.6	71	-1.1
Aug	71	16.9	-40	3.5	36	2.1	63	17.2	-49	4.0	-18	1.4
Sep	67	13.9	18	0.5	0	0.9	54	13.9	-8	-0.1	1	0.1
Oct	63	10.0	-7	-3.8	-17	1.0	46	9.6	-10	-3.4	0	0.8
Nov	79	5.3	-36	2.2	18	-0.2	59	4.5	-30	2.0	32	-0.4
Dec	88	2.4	-2	0.8	-21	0.2	67	1.4	-5	0.3	-34	-1.3

4.2.2 Assessment of quality parameters

Sub-samples (graded > 40 mm) of 5 kg/plot were washed with tap-water, and weight of wet potato tubers in water was measured with a KUV 2000-balance (Fischer KG, Bielefeld, Germany). Specific gravity was calculated according to Haase (2003/2004) (Equation 1).

(1) Specific gravity = weight in air / (weight in air – weight in water)

Subsequently, dry matter concentration was calculated using a linear regression (Equation 2).

(2) Dry matter (%) = -210 + (213 x specific gravity).

For further analyses, 32 tubers per sample were cut into cubes of 10 × 10 × 20 mm with a vegetable cutter (model TR 21, Pefra, Germany). An aliquot of 500 g was lyophilised by a freeze dryer (model alpha 1-4, Christ, Germany) and ground for further analysis (laboratory mill). Another aliquot of 500 g was crushed finely with a kitchen mixer (model Combimax, Braun, Germany).

Dry matter concentration of the mashed samples was calculated after measuring the weight loss by heating at 105 °C in an oven dryer (AACC, 1993a). The remaining moisture concentration of the lyophilised and ground samples was also measured as weight loss at 105 °C in an oven dryer (AACC, 1993b). Tuber concentration of reducing sugars (glucose, fructose) and sucrose were determined enzymatically in lyophilised samples according to Boehringer (1995), and detected at 365 nm by a U 1100 Spectrophotometer (Hitachi, Germany).

Par-fried French fries were produced from tuber samples (5 kg per plot) by abrasive peeling, washing, strip cutting, sliver elimination, blanching, washing, frying (130 °C, 3 min), cooling, and freezing in a semi-technical processing line. The frozen samples were finished in a gastronomic-scale fryer (175 °C, 2.5 min) and sensory quality of fries was assessed by a panel of up to 5 panellists experienced in sensory assessment for the weighted characteristics colour (2x), texture (3x), taste and odour (5x). The values could range between 1 and 5. A quality score of > 3.5 means that the lot is well suited for processing, while a score < 3.0 indicates an unacceptable quality of fries.

Tuber samples (5 kg per plot) for potato crisp production were sliced at 1.2 mm by an Urschel industrial slicer (model CC (modified), Urschel Laboratories Inc., Valparaiso, Indiana, USA), washed, and fried (170 °C, 3 min) in a semi-technical processing line using organic palm oil (palm olein deodorized, CARE Naturkost, Sittensen, Germany). Crisp quality was assessed by instrumental analysis of colour (MINOLTA CR 310, Langenhagen, Germany, using the CIE standard of lightness (L*) and colouration (a* and b*). An L-value above 62.6 means that tubers are suitable for processing, according to the Bundessortenamt (2004). L-values > 69.7 represent highest quality standards.

All analyses were conducted twice, shortly after harvest and following four months of storage at 8 °C under controlled conditions without any sprout suppression.

4.2.3 Statistical analysis

The dependent variables were analysed by fitting a linear mixed model (Piepho et al. 2003). Analysis of variance and estimation of least square means and standard errors were performed with the procedure MIXED of the software package SAS 9.1.3 (SAS Institute 2004). Denominator degrees of freedom were approximated by the Kenward-Roger method (Kenward and Roger 1997). Residuals were checked for normal (Gaussian) distribution and homogeneity of variance with PROC UNIVARIATE and PROC GPLOT. If necessary, data were either log- or square-root-transformed, and subjected to analysis of variance. LSMEANS and their associated 95% confidence limits means were transformed back to the original scale.

Experiment 1 was designed as a two-factorial split-plot trial. Factors “fertilization” (FERT) and “cultivar” (CV) were combined with factors “year” (YEAR) and “storage“ (STOR) in the fixed part of the model. The complete replicate (REP) was nested within YEAR and combined with FERT treated as a random effect (main plot error).

In experiment 2, the five factors “preceding crop” (PC), “cultivar” (CV) and “pre-sprouting” (PRS), “year” (YEAR) and “storage” (STOR) were combined, yielding a full five-factorial structure in the fixed part of the mixed model. According to randomization structure, REP was nested within YEAR and combined with PC treated as a random effect (main plot error).

When quality of French fries and crisps was analysed for samples from Exps 1 and 2, the factor CV was omitted, since each cultivar was processed into either French fries (cv. Agria) or crisps (cv. Marlen).

Experiment 3 was analysed with CV, YEAR and STOR as fixed factors, replication nested within YEAR as a random effect.

In all three experiments replications (REP) were treated as fixed effects. Since all dependent variables were estimated at two points of time (at harvest and after storage), STOR was treated as repeated measurements (Piepho et al. 2004).

In Tables 6 to 9, simple means are presented. The least significant differences (LSD) given at the bottom of each table are based on a full-factorial analysis and can be used for comparisons of means between two treatment factor levels at a given combination of the other factors. When factors shared the same LSD, the former are separated by a comma.

4.3 Results

At both locations, the dry and warm weather during June and August 2003 prevented the epidemic spread of P. infestans and resulted in modest wilting and slow senescence of the canopy. A moderate development of the fungus was recorded in 2004, starting in mid-July and gradually leading to premature death of the canopy, although not before the end of August. The two cultivars used in Exps 1 and 2 did not differ in terms of disease development, nor did the other factor treatments affect late blight epidemics. At the end of July in 2004, all cultivars except Agria, Marella, Marlen and Marena (Exp. 3) had more than 70% infected leaf area (data not shown).

In Tables 4 and 5 the results from analysis of variance are presented. Depending on the individual trait, levels of significance for treatment effects and their interactions varied strongly, and we do not present all the trait-specific significant interactions in individual tables. While in Tables 6-9 simple means are presented, only the relevant comparisons of the marginal mean values, i.e. when siginificance of treatment effects and/or their interactions was established, are described in results and discussed subsequently.

Table 4.4: *P*-values for tests of sources of variation for internal quality traits of tubers

a) Exp.1	Numerator d.f.	Dry matter concentration (% in FW)	Glucose (mg kg^{-1})	Fructose (mg kg^{-1})	Glucose + fructose (mg kg^{-1})
FERT	4	**<0.0001**	0.1019	0.1124	0.1039
CV	1	**<0.0001**	0.4736	**0.0189**	0.1791
YEAR	1	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
STOR	1	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
FERT•YEAR	4	**0.0381**	0.2068	0.2770	0.2238
FERT•STOR	4	0.7559	0.7013	0.3680	0.5648
FERT•CV	4	**0.0007**	0.3555	0.6114	0.4567
YEAR•STOR	1	0.6366	**<0.0001**	**<0.0001**	**<0.0001**
CV•STOR	1	0.2016	0.9498	0.9783	0.9593
CV•YEAR	1	**<0.0001**	**0.0263**	0.3477	0.0752
FERT•YEAR•STOR	4	0.7266	0.5281	0.5375	0.5231
FERT•CV•YEAR	4	0.0993	0.4642	0.5807	0.4959
FERT•CV•STOR	4	0.4272	0.3307	0.2695	0.3105
FERT•CV•YEAR•STOR	5	0.1455	0.3214	0.2784	0.2977
REP	3	0.7220	0.1648	0.1322	0.1485
b) Exp.2					
PC	3	0.1861	**0.0004**	**<0.0001**	**<0.0001**
PRS	1	**<0.0001**	0.2385	0.7874	0.4680
PC•PS	3	**0.0471**	0.1143	0.2010	0.1459
CV	1	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
PC•CV	3	**0.0010**	**0.0216**	0.0614	**0.0239**
CV•PRS	1	0.3147	**<0.0001**	**<0.0001**	**<0.0001**
PC•CV•PRS	3	0.6483	0.1608	0.8641	0.3208
YEAR	1	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
PC•YEAR	3	0.1490	**0.0012**	**0.0002**	**0.0003**
PRS•YEAR	1	**<0.0001**	**0.0025**	**0.0260**	**0.0040**
PC•PRS •YEAR	3	0.7706	0.0656	0.2577	0.1145
CV•YEAR	1	**0.0105**	**<0.0001**	0.0999	**0.0013**
PC•CV •YEAR	3	0.9688	**0.0094**	**0.0002**	**0.0022**
CV•PRS•YEAR	1	0.4558	**<0.0001**	**<0.0001**	**<0.0001**
PC•CV•PRS•YEAR	3	0.7654	**0.0283**	**0.0221**	**0.0251**
STOR	1	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
PC•STOR	3	0.8793	**0.0024**	**<0.0001**	**0.0005**
PRS•STOR	1	0.9863	0.2222	**0.0405**	0.1181
PC•PRS•STOR	3	0.7375	0.1246	0.0950	0.1201
CV•STOR	1	0.0528	**<0.0001**	**<0.0001**	**<.0001**
PC•CV•STOR	3	0.1328	0.5221	0.3302	0.4609
CV•PRS•STOR	1	0.2107	0.0568	**<0.0001**	**0.0070**
PC•CV•PRS•STOR	3	0.7177	0.1820	0.8940	0.4039
YEAR•STOR	1	0.1795	**<0.0001**	**<0.0001**	**<0.0001**
PC•YEAR•STOR	3	0.1058	0.1300	0.0644	0.0883
PRS•YEAR•STOR	1	0.6520	0.2128	**0.0004**	**0.0352**
PC•PRS•YEAR•STOR	3	0.8105	0.8772	0.3967	0.7730
CX•YEAR•STOR	1	0.5631	**<0.0001**	**<0.0001**	**<0.0001**
PC•CV•YEAR•STOR	3	0.4782	0.6998	0.0696	0.5725
CV•PRS•YEAR•STOR	1	0.1849	**<0.0001**	**<0.0001**	**<0.0001**
PC•CV•PRS•YEAR•STO	3	0.1526	**0.0082**	**0.0472**	**0.0106**
REP	3	0.1132	**0.0159**	**0.0083**	**0.0065**

Table 4.4 continued

	Numerator d.f.	Dry matter concentration (% in FW)	Glucose (mg kg^{-1})	Fructose (mg kg^{-1})	Reducing sugars (mg kg^{-1})
c) Exp.3					
REP	3	0.4560	0.4504	0.3509	0.3778
CV	9	**<0.0001**	**<.0001**	**<0.0001**	**<0.0001**
YEAR	1	0.0879	**0.0001**	**<0.0001**	**<0.0001**
CV•YEAR	9	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
STOR	1	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
CV•STOR	9	0.1831	**<0.0001**	**<0.0001**	**<0.0001**
YEAR x STOR	1	**0.0027**	**<0.0001**	**<0.0001**	**<0.0001**
CV x YEAR x STOR	9	0.7822	**<0.0001**	**<0.0001**	**<0.0001**

P-values in bold represent significant effects at the 5% level.

Table 4.5: Test of fixed effects: *P*-values for tests of sources of variation for French fry and crisp quality of potatoes in Exps 1-3. *P*-values in bold represent significant effects at the 5% level.

Source of variation	Numerator d.f.	French fry colour	French fry texture	French fry taste/odour	French fry quality score	Crisp colour (L-value)
a) Exp. 1						
FERT	4	0.7570	0.0576	0.5212	0.5234	0.2850
YEAR	1	0.9047	0.4191	0.0909	0.0598	**<0.0001**
FERT•YEAR	4	**0.0162**	**0.0048**	0.6382	0.2147	0.3028
STOR	1	**<0.0001**	**0.0459**	**0.0162**	**0.0088**	**<.0001**
FERT•STOR	4	0.7708	0.9183	0.3969	0.5255	0.3274
YEAR•STOR	1	0.2091	0.2485	0.1026	0.1707	**<0.0001**
FERT•YEAR•STOR	4	0.3613	0.3613	**0.0260**	**0.0448**	0.8398
REP	3	0.1814	**0.0473**	0.9566	0.8201	0.7923
b) Exp. 2						
PC	3	**0.0310**	0.6170	0.1511	0.0715	**0.0004**
PRS	1	**0.0192**	0.5434	0.6814	0.6192	0.6205
PC•PS	3	0.2868	0.4003	0.2934	0.7109	0.2726
YEAR	1	**<0.0001**	**<0.0001**	**0.0011**	**<0.0001**	**<0.0001**
PC•YEAR	3	0.2758	0.1073	0.3995	0.0759	0.1877
PRS•YEAR	1	0.8213	0.4902	0.1478	0.2411	0.6633
PC•PRS•YEAR	3	0.4450	0.8303	0.0532	0.1557	0.5021
STOR	1	**<0.0001**	0.1338	**<0.0001**	**<0.0001**	**<0.0001**
PC•STOR	3	0.7716	0.5431	0.3285	0.7516	0.2937
PRS•STOR	1	0.9275	0.7646	**0.0499**	0.2393	0.9970
PC•PRS•STOR	3	0.5462	0.7092	0.4617	0.3780	0.4706
YEAR•STOR	1	0.0879	0.2840	0.4836	0.7143	**<0.0001**
PC•YEAR•STOR	3	0.2398	0.4867	0.0908	0.2415	0.2073
PRS•YEAR•STOR	1	0.9934	0.8278	0.1099	0.2171	0.4002
PC•PRS•YEAR•STOR	3	0.0704	0.9521	**0.0266**	0.0821	0.8662
REP	3	0.5628	0.1551	0.4020	0.8859	0.2391
c) Exp. 3						
REP	3	0.7688	0.1619	0.3744	0.5609	0.2149
CV	8	**<0.0001**	0,0599	**<.0001**	**<0.0001**	**<0.0001**
YEAR	1	**0.0008**	**0.0182**	**0.0050**	**0.0027**	**<0.0001**
CV•YEAR	8	**0.0159**	**0.0027**	0.1162	0.0542	**<0.0001**
STOR	1	**<0.0001**	**0.0053**	**<0.0001**	**<0.0001**	**<0.0001**
CV•STOR	8	**0.0002**	0.0579	**0.0003**	**0.0010**	**<0.0001**
YEAR•STOR	1	0.1810	0.0979	0.9167	0.2479	**<0.0001**
CV•YEAR•STOR	6	**0.0258**	0.2738	0.3461	0.0976	0.7031

4.3.1 Dry matter concentration in tubers

Dry matter (DM) concentration in tubers was significantly affected by fertilization (Exp. 1), cultivar (Exps 1-3) and pre-sprouting of tubers (Exp. 2). Moreover, significant interactions of these treatments with the year were established. Factor storage was also significant in every experiment, while in Exp. 3, the response to storage was not consistent over the two seasons (Table 4.4).

Fertilization

In Exp. 1, application of mineral K (potassium sulphate) or combined K and organic N (potassium sulphate + horn grits) caused a significant decrease in DM concentration (-0.9 and -1.2%) in 2003 as compared to the control. In 2004, all types of fertilization reduced DM concentration significantly and reduction was strongest when K and N were applied together (-2.1%), as compared to sole application of either K (-0.6%) or N (-1.2%) (Table 4.6-a).

Table 4.6: DM concentration (%) in tubers at harvest and after storage

		2003		2004	
		At harvest	After storage	At harvest	After storage
a) Exp. 1					
Fertilization	Cultivar				
Cattle manure	Agria	22.4	22.4	19.6	20.4
	Marlen	23.0	23.5	21.9	21.6
Potassium sulphate	Agria	21.8	22.0	20.5	20.7
	Marlen	21.9	23.1	22.6	23.2
Potassium sulphate + horn grits	Agria	21.1	21.0	18.8	19.5
	Marlen	22.3	23.1	21.2	21.6
Horn grits	Agria	21.3	21.7	19.5	20.1
	Marlen	23.3	23.6	22.2	23.0
Control	Agria	22.2	22.5	21.4	21.7
	Marlen	23.5	24.1	22.9	23.5
LSD (5%) [a]					
CV, STOR			0.74		
YEAR			0.91		
FERT			1.03		

Table 4.6 continued

			2003		2004	
			At harvest	After storage	At harvest	After storage
b) Exp. 2						
Preceding crop	Cultivar	Pre-sprouting				
Peas	Agria	yes	24.3	24.2	22.5	22.5
		no	23.7	24.2	21.7	20.5
	Marlen	yes	21.3	27.6	25.4	26.0
		no	26.9	27.2	24.1	25.0
Oat	Agria	yes	24.8	24.9	22.1	23.0
		no	25.4	25.1	21.2	21.4
	Marlen	yes	27.2	27.8	25.2	25.4
		no	27.5	28.1	24.4	25.4
Alfalfa-grass/clover	Agria	yes	23.7	23.8	21.5	22.5
		no	24.0	24.3	20.7	21.2
	Marlen	yes	27.6	27.1	25.7	26.4
		no	27.4	27.6	24.2	25.3
Winter wheat	Agria	yes	24.9	25.3	22.6	23.0
		no	24.8	25.1	20.6	21.3
	Marlen	yes	27.6	27.6	25.2	26.0
		no	27.2	27.9	23.8	24.4
LSD (5%)[1]						
CV, PRS, STOR					0.95	
PC/YEAR					1.07	

c) Exp. 3

Cultivar	2003 At harvest	2003 After storage	2004 At harvest	2004 After storage
Premiere	25.2	25.2	26.6	28.8
Velox	22.4	22.9	22.8	24.8
Camilla	25.0	25.5	23.2	24.1
Carmona	25.5	27.2	24.0	25.7
Delikat	26.1	27.4	28.1	30.2
Agria	25.6	25.6	24.9	25.7
Freya	26.9	27.7	26.6	28.0
Marlen	26.4	26.7	26.9	28.7
Marena	25.1	25.1	24.9	25.0
Saturna	27.7	27.9	28.7	29.7
LSD (5%) [a]				
CV, YEAR			1.44	
STOR			1.40	

[a] The least significant differences (LSD) are given for main effects only. Note that some factors share the same LSD. For significances of main effects and interactions see Table 4.4

Preceding crop and pre-sprouting

In Exp. 2, the leguminous preceding crops (peas and alfalfa-grass/clover) both caused significantly lower tuber DM concentrations than the two cereal grains in cv. Agria (Table 4.6). With cv. Marlen, tuber DM concentration was significantly lower only after peas. In 2004, pre-sprouting increased DM concentration of tubers significantly by 1.2% (absolute) (Tanle 4.6-b).

Storage and year

After storage, DM concentration was significantly higher (by 0.5% in Exp. 1 and 0.6% in Exp. 2) than at harvest (Table 4.6-a,b). On average of all cultivars tested, the increase in tuber DM due to storage amounted to +0.5% in 2003, and +1.4% in 2004 (Exp. 3). In cvs Camilla and Carmona, tuber DM was significantly lower in 2004 compared to 2003, whereas in others (cvs Premiere, Velox, Delikat, Marlen and Saturna) response to year was vice versa (Table 4.6-c).

Cultivar

Comparing between the different experiments, DM concentration (average of both years) of the two reference cultivars ranged between 21.0 (Exp. 1), 23.1 (Exp. 2) and 25.5% (Exp. 3) for cv. Agria, and 22.7, 26.1 and 27.2% for cv. Marlen, respectively.

4.3.2 Reducing sugar concentration of tubers

Storage and year

For the 2003 crop, glucose, fructose and total reducing sugar concentrations increased during storage, but the final concentrations after four months were still very low (Table 4.7). In 2004, the initial concentrations at harvest were comparatively higher than in 2003, and the increase during storage was appreciable (Exps 1-3). In Exp. 2, the interaction between year and storage was stronger than any of the significant and up to 5-way interactions (Table 4.4-b). The relative increase in tuber glucose and fructose concentrations during storage amounted to 44 and 145% for the 2003 crop, and to 212 and 998% for the 2004 crop, respectively (Table 4.7-b).

The increase in the total reducing sugars (glucose + fructose) concentrations during storage was very small after the 2003 harvest and much larger after the 2004 harvest (Exps 1 and 2). The average concentrations of reducing sugars after the storage period were also much higher for tubers from the 2004 harvest than from the 2003 harvest (Table 4.7).

Cultivar

At a very low level, glucose concentration was significantly higher in cv. Marlen in 2003 than in cv. Agria, while no difference between the two cultivars was established in 2004 (Exp. 1). Regarding fructose, the concentration in cv. Marlen was lower than in cv. Agria in both years (Table 4.7-a). In Exp. 3, the increase in glucose or fructose concentrations with storage of the cultivars tested was not consistent in the two experimental seasons. The relative increase of, e.g., glucose ranged between +12% (cv. Marena) and 854% (cv. Delikat) for tubers from the 2003 harvest and between +220% (cvs Premiere and Saturna) and 694% (cv. Carmona) for tubers from the 2004 harvest (Table 4.7-c).

In Exp. 3, only cvs Premiere, Velox, Carmona and Delikat showed a significant increase in reducing sugars concentrations during storage in 2003, whereas after the 2004 harvest all cultivars except cv. Marena showed a significant increase (Table 4.7-c).

Preceding crop and pre-sprouting

Tuber concentrations of total reducing sugars were affected by preceding crop, but several and up to five-fold significant interactions (PC X CV X PRS X YEAR X STOR) occurred in Exp. 2 (Table 4-b). In 2003, pre-sprouting had no effect on reducing sugar concentrations, while in 2004 it increased the concentrations in cv. Marlen, but decreased it in cv. Agria (Table 7b).

Table 4.7: Concentration of glucose and fructose in tubers at harvest and after storage

a) Exp. 1		Glucose (g kg^{-1} FW)				Fructose (g kg^{-1} FW)				Glucose + fructose (g kg^{-1} FW)			
		2003		2004		2003		2004		2003		2004	
Fertilization	Cultivar	At harvest	After storage	At harvest	After storage	At harvest	After storage	At harvest	After storage	At harvest	After storage	At harvest	After storage
Cattle manure	Agria	0.05	0.13	0.15	0.69	0.01	0.07	0.03	0.43	0.05	0.20	0.18	1.12
	Marlen	0.06	0.15	0.15	0.66	0.02	0.07	0.06	0.41	0.08	0.22	0.20	1.07
Potassium sulphate	Agria	0.04	0.10	0.11	0.56	0.01	0.04	0.02	0.35	0.04	0.14	0.13	0.91
	Marlen	0.05	0.14	0.13	0.59	0.01	0.07	0.04	0.38	0.07	0.21	0.18	0.97
Potassium sulphate + HG	Agria	0.05	0.07	0.17	0.69	0.01	0.03	0.04	0.42	0.06	0.10	0.21	1.11
	Marlen	0.07	0.15	0.15	0.73	0.02	0.08	0.06	0.46	0.09	0.23	0.21	1.19
Horn grits (HG)	Agria	0.06	0.08	0.17	0.75	0.01	0.03	0.03	0.45	0.07	0.11	0.21	1.20
	Marlen	0.06	0.19	0.17	0.73	0.01	0.11	0.06	0.48	0.08	0.30	0.23	1.21
Control	Agria	0.04	0.10	0.17	0.83	0.00	0.03	0.02	0.48	0.04	0.13	0.19	1.30
	Marlen	0.07	0.14	0.17	0.60	0.02	0.08	0.06	0.39	0.09	0.22	0.22	0.99
LSD (5%) [a]													
CV, STOR		0.113				0.066				0.176			
YEAR		0.115				0.066				0.179			
FERT		0.115				0.066				0.179			

Table 4.7 continued

b) Exp. 2			Glucose (g kg^{-1} FW)				Fructose (g kg^{-1} FW)				Glucose + fructose (g kg^{-1} FW)			
			2003		2004		2003		2004		2003		2004	
Preceding crop	Cultivar	Pre-sprouting	At harvest	After storage	At harvest	After storage	At harvest	After storage	At harvest	After storage	At harvest	After storage	At harvest	After storage
Peas	Agria	yes	0.11	0.19	0.21	0.70	0.04	0.13	0.03	0.44	0.15	0.32	0.24	1.13
		no	0.10	0.15	0.29	1.00	0.04	0.08	0.04	0.56	0.13	0.23	0.33	1.56
	Marlen	yes	0.08	0.10	0.27	0.78	0.02	0.04	0.10	0.52	0.10	0.14	0.37	1.30
		no	0.05	0.12	0.22	0.64	0.01	0.05	0.06	0.40	0.07	0.16	0.27	1.04
Oats	Agria	yes	0.13	0.16	0.19	0.55	0.04	0.09	0.01	0.35	0.16	0.25	0.20	0.90
		no	0.11	0.14	0.31	0.89	0.03	0.07	0.01	0.54	0.14	0.21	0.32	1.44
	Marlen	yes	0.13	0.12	0.21	0.57	0.04	0.06	0.08	0.36	0.16	0.17	0.29	0.94
		no	0.07	0.11	0.15	0.50	0.02	0.04	0.04	0.34	0.08	0.15	0.18	0.83
Alfalfa-grass/ clover	Agria	yes	0.15	0.29	0.28	0.85	0.07	0.21	0.02	0.46	0.22	0.50	0.30	1.30
		no	0.19	0.19	0.26	0.97	0.07	0.14	0.01	0.59	0.26	0.32	0.27	1.56
	Marlen	yes	0.08	0.13	0.21	0.76	0.02	0.06	0.07	0.50	0.11	0.19	0.29	1.26
		no	0.07	0.14	0.20	0.52	0.02	0.07	0.05	0.37	0.09	0.22	0.25	0.90
Winter wheat	Agria	yes	0.09	0.14	0.23	0.88	0.02	0.06	0.03	0.50	0.11	0.20	0.26	1.38
		no	0.10	0.17	0.34	0.97	0.03	0.08	0.03	0.60	0.12	0.24	0.37	1.56
	Marlen	yes	0.11	0.12	0.21	0.59	0.03	0.05	0.08	0.41	0.14	0.17	0.29	1.00
		no	0.07	0.10	0.17	0.63	0.01	0.03	0.05	0.39	0.08	0.14	0.23	1.03
LSD (5%) [a]														
CV, PRS, STOR				0.093				0.047				0.135		
PC, YEAR				0.093				0.048				0.134		

Table 4.7 continued

c) Exp. 3	Glucose (mg kg^{-1} FW)				Fructose (mg kg^{-1} FW)				Glucose + fructose (mg kg^{-1} FW)			
	2003		2004		2003		2004		2003		2004	
Cultivar	At harvest	After storage	At harvest	After storage	At harvest	After storage	At harvest	After storage	At harvest	After storage	At harvest	After storage
Premiere	0.73	3.04	1.68	5.39	0.33	2.56	0.57	3.62	1.07	5.60	2.25	9.00
Velox	0.37	1.95	1.45	5.87	0.23	1.99	0.63	4.35	0.59	3.95	2.09	10.22
Camilla	0.15	0.53	0.86	4.40	0.06	0.42	0.24	2.83	0.21	0.95	1.11	7.24
Carmona	0.16	1.30	0.48	3.84	0.08	1.07	0.15	2.55	0.24	2.37	0.63	6.40
Delikat	0.26	2.52	1.27	6.62	0.10	1.85	0.50	4.65	0.36	4.37	1.77	11.27
Agria	0.05	0.16	0.21	1.22	0.00	0.09	0.03	0.84	0.06	0.25	0.25	2.06
Freya	0.11	0.20	0.26	1.43	0.04	0.09	0.06	1.00	0.15	0.29	0.32	2.43
Marlen	0.08	0.14	0.16	0.89	0.02	0.07	0.06	0.64	0.10	0.21	0.22	1.53
Marena	0.16	0.17	0.17	0.67	0.03	0.10	0.03	0.47	0.18	0.27	0.20	1.14
Saturna	0.09	0.22	0.34	1.09	0.03	0.13	0.11	0.78	0.12	0.35	0.45	1.87
LSD (5%) [a]												
CV, YEAR			0.570				0.352				0.912	
STOR			0.577				0.358				0.928	

[a] The least significant differences (LSD) are given for main effects only. Note that some factors share the same LSD. For significances of main effects and interactions, see Table 4.4

4.3.3 Organoleptic quality of finished French fries and colour of crisps

Fertilization

In Exp. 1, the interaction between fertilization and year was significant for colour and texture, as was the interaction between fertilization, year and storage for taste and quality score of French fries (Table 4.5). In 2003, fry colour values of fries from crops fertilized with cattle manure were significantly lower than those of the unfertilized control (4.4) (Table 4.5-a). In 2004, cattle manure gave significantly higher colour values, namely 4.6, than pure horn grits application (3.7). In 2003, significantly higher values for texture were measured for potassium sulphate (3.1) than for the control (2.6). In 2004, fries from the unfertilized control had the significantly highest (3.0) texture values (Table 4.8-a).

Preceding crop and pre-sprouting

In Exp. 2, fry colour was affected signifcantly by preceding crop and pre-sprouting, year and storage (Table 4.5-b). Alfalfa-grass/clover consistently caused lower values for French fry colour (3.7) compared with other preceding crops, whereas the preceding crop did not affect the texture, taste or the quality score (Table 4.5-b). Fry colour values were significantly higher when seed-tubers were presprouted (4.1 instead of 3.9). When tubers had not been presprouted, taste of French fries suffered markedly from storage. When tubers were presprouted, storage did not cause changes in fry taste (Table 4.8-b).

Storage and year

Significant interactions between storage, year and fertilization were established in Exp. 1 for fry taste and quality score (Table 4.5). Changes in fry taste due to storage were observed after fertilization with cattle manure (decrease) or potassium sulphate + horn grits (increase) in tubers from the 2003 harvest, and potassium sulphate + horn grits (decrease) in tubers from the 2004 harvest (Table 4.8-a). A significant decrease of the fry quality score during storage was established only after cattle manure or potassium sulphate application (-0.65 and -0.55, respectively) with tubers from the 2003 harvest, and no fertilization (control) with tubers from the 2004 harvest (-0.58). In terms of colour and texture, storage consistently caused lower values, independently of fertilization or year (Table 4.8-a). In Exp. 2 the values of all assessed quality traits and the quality score were higher in 2003 compared with 2004. After storage, colour, taste and the quality score were lower than at harvest

(Table 4.8-b). In Exp. 3, the year and storage exerted a significant impact upon the parameters relevant for French fry quality. However, for each trait, interactions with other treatment factors occurred: Response of fry colour, taste and quality score to storage depended on the cultivar, whereas fry colour and texture of the different cultivars depended on the year (Table 4.5-c).

Cultivar

The two cultivars giving consistently very high values for colour of French fries were Agria and Marena (Table 4.8-c). Yet, colour of cultivars interacted significantly with storage and also year (Table 4.5-c). A marked decrease in fry colour values due to storage was established for Velox, Carmona, Delikat and Marena in 2003, but only for Premiere and Agria in 2004. Values for texture were significantly higher for cvs Premiere, Delikat and Marella and lower for Velox in 2003 as compared to 2004. The decrease in taste due to storage was significant for cvs Premiere and Velox and for Carmona and Delikat in 2003, but there was no assessment of samples for the latter two cultivars after the 2004 storage. The reduction in the overall quality during storage was significant for all cultivars except Camilla and Marena (Table 4.8-c).

Table 4.8: Quality scores[b] of colour, texture, taste / odour and quality index of French fries at harvest and after storage (cv. Agria in Exps 2 and 3)

a) Exp. 1	Colour				Texture			
	2003		2004		2003		2004	
	At harvest	After storage	At harvest	After storage	At harvest	After storage	At harvest	After storage
Cattle manure	4.3	2.9	5.0	4.3	2.8	2.8	2.5	2.8
Potassium sulphate	4.5	4.0	4.5	4.0	3.3	3.0	2.3	3.0
Potassium sulphate + horn grits	4.5	4.3	4.5	3.5	2.5	2.5	2.3	3.0
Horn grits	4.5	4.0	4.3	3.3	2.5	3.0	2.5	2.8
Control	4.5	4.3	4.8	3.5	2.5	2.8	3.0	3.0
LSD (5%) [a]								
FERT	0.86				0.63			
STOR	0.91				0.78			
YEAR	0.83				0.62			

	Taste/odour				Quality score			
	2003		2004		2003		2004	
	At harvest	After storage	At harvest	After storage	At harvest	After storage	At harvest	After storage
Cattle	4.5	3.5	4.3	3.8	3.9	3.3	3.9	3.6
Potassium sulphate	5.0	4.3	4.3	4.0	4.4	3.8	3.7	3.7
Potassium sulphate + horn grits	4.0	5.0	4.8	3.8	3.7	4.1	4.0	3.5
Horn grits	4.5	4.7	4.3	3.8	3.9	4.0	3.7	3.3
Control	4.3	4.3	4.5	4.0	3.8	3.8	4.1	3.5
LSD (5%) [a]								
FERT	0.91				0.55			
STOR	0.83				0.56			
YEAR	0.88				0.55			

Table 4.8 continued

b) Exp. 2

		Colour				Texture			
		2003		2004		2003		2004	
Preceding crop	Pre-sprouting	At harvest	After storage	At harvest	After storage	At harvest	After storage	At harvest	After storage
Peas	Yes	4.8	4.0	3.8	4.0	3.5	3.0	3.3	3.0
	No	4.3	3.8	4.0	3.5	3.5	3.5	3.3	3.0
Oats	Yes	4.8	4.5	4.0	3.3	4.3	3.5	3.0	3.0
	No	4.8	4.3	4.0	3.8	4.3	3.3	3.0	3.0
Alfalfa-grass /clover	Yes	4.3	3.5	4.0	3.5	3.8	3.5	3.3	3.0
	No	4.3	3.3	3.0	3.5	3.4	3.6	2.9	3.0
Winter wheat	Yes	5.0	4.3	4.0	3.8	3.5	3.5	2.8	3.0
	No	4.5	4.0	4.0	3.0	4.3	4.0	3.1	3.0
LSD (5%) [a]									
STOR / PS		0.67				0.91			
YEAR /PC		0.71				0.87			

		Taste/odour				Quality score			
Preceding crop	Pre-sprouting								
Peas	Yes	4.3	4.0	4.5	4.3	4.1	3.7	4.0	3.8
	No	5.0	4.8	4.5	3.8	4.4	4.2	4.0	3.5
Oats	Yes	4.8	5.0	4.0	4.0	4.6	4.5	3.7	3.6
	No	5.0	4.0	4.3	4.0	4.7	3.8	3.8	3.7
Alfalfa-grass/ clover	Yes	4.5	3.8	4.0	4.0	4.2	3.6	3.8	3.6
	No	4.3	4.0	4.0	3.8	4.0	3.8	3.5	3.5
Winter wheat	Yes	5.0	4.5	4.5	4.3	4.6	4.2	3.9	3.8
	No	4.8	4.8	4.9	2.8	4.6	4.4	4.2	2.9
LSD (5%) [a]									
STOR/PS		0.77				0.58			
YEAR/PC		0.79				0.58			

Table 4.8 continued

c) Exp. 3	Colour				Texture			
	2003		2004		2003		2004	
Cultivar	At harvest	After storage	At harvest	After storage	At harvest	After storage	At harvest	After storage
Premiere	3.3 [b]	2.5	2.8	1.5	4.3	3.5	3.3	3.3
Velox	4.8	2.3	3.3	2.3	2.8	2.5	3.3	3.5
Camilla	4.5	3.5	2.8	2.0	3.3	3.8	3.3	3.3
Carmona	4.8	2.3	4.0	nd [d]	3.8	3.3	3.0	nd
Delikat	4.0	2.3	3.0	nd	3.3	3.3	2.5	nd.
Agria	4.8	3.6	4.8	3.0	3.8	3.0	3.0	3.3
Freya	3.6	3.0	3.3	2.3	3.6	3.3	3.3	2.8
Marella	3.8	3.3	3.3	3.3	5.0	3.3	3.3	2.6
Marena	4.8	3.5	3.8	3.5	3.8	3.5	3.3	2.8
LSD (5%) [a]								
CV	0.76				0.79			
YEAR	0.70				0.79			
STOR	0.77				0.86			

	Taste/odour				Quality score			
Cultivar								
Premiere	4.3	2.5	3.0	1.8	4.1	2.8	3.0	2.2
Velox	4.3	2.8	3.3	2.3	3.9	2.6	3.3	2.6
Camilla	3.5	4.0	2.8	2.0	3.6	3.8	2.9	2.4
Carmona	4.8	3.0	3.8	nd	4.5	2.9	3.6	nd
Delikat	4.8	2.8	3.3	nd	4.2	2.8	3.0	nd
Agria	4.8	4.3	4.5	3.8	4.5	3.8	4.1	3.5
Freya	4.6	4.0	4.3	3.8	4.1	3.6	3.8	3.2
Marella	4.8	4.0	4.0	4.0	4.6	3.6	3.6	3.4
Marena	4.0	4.5	4.0	4.0	4.1	4.0	3.7	3.5
LSD (5%) [a]								
CV	0.91				0.57			
YEAR	0.91				0.57			
STOR	0.99				0.61			

[a] See comment on Table 4.6

nd. = not determined

[b] The 5-point scale and rating provides a scheme for assessment of quality attributes and the quality score of French fries, ranging from:

5 = fulfilment of requirements

4 = insignificant deviations

3 = considerable deviation

2= distinct deviation

1 = strong deviation

Colour of crisps

Preceding crop, storage and year

In the three experiments, crisp lightness was mainly influenced by preceding crop (Exp. 1), year (Exps 1-3) and storage (Exps 1-3) (Table 4.5). Significantly lighter crisps (higher L-values) were assessed after winter wheat than after the two leguminous preceding crops, while after oats crisp colour values were lower only than those after alfalfa-grass/clover (Table 4.9-b). In two experiments (Exps 1 and 2) the L-value was not influenced by storage in 2003, while in 2004, it decreased appreciably during storage (Table 4.9-a,b).

Table 4.9: Crisps colour (L-value)[b] at harvest and after storage (cv. Marlen in Exps. 2 and 3)

a) Exp. 1	Crisps colour (L-value) [b]			
	2003		2004	
Fertilization	At harvest	After storage	At harvest	After storage
Cattle manure	71.3	70.8	71.3	64.1
Potassium sulphate	69.1	69.8	71.3	64.6
Potassium sulphate + horn grits	70.9	70.0	71.5	63.1
Horn grits	70.4	70.6	72.2	64.1
Control	70.8	70.6	72.0	65.1
LSD (5%) [a]				
FERT			1.75	
CV, STOR			1.58	
YEAR			1.72	

b) Exp. 2					
Preceding crop	Pre-sprouting				
Peas	Yes	70.1	70.1	71.1	65.4
	No	68.9	70.5	69.7	64.7
Oats	Yes	69.9	70.4	70.0	66.6
	No	70.2	70.5	70.3	67.0
Alfalfa-grass /clover	Yes	68.5	68.7	70.0	65.6
	No	69.3	69.7	70.6	64.6
Winter wheat	Yes	70.2	70.7	71.5	66.4
	No	69.6	69.9	71.9	66.1
LSD (5%) [a]					
STOR, PS				1.76	
YEAR, PC				1.66	

c) Exp. 3	Crisps colour (L-value) [b]			
	2003		2004	
Cultivar	At harvest	After storage	At harvest	After storage
Carmona	70.1	62.8	69.1	50.8
Delikat	67.7	58.1	62.7	44.7
Agria	68.5	68.9	70.4	nd
Marlen	70.5	70.5	71.0	62.8
Saturna	69.3	69.2	71.2	62.2
LSD (5%) [a]				
CV			0.76	
YEAR			0.70	
STOR			0.77	

[a] See comment on Table 4.6

[b] The 10-point scale and L-value rating provides a scheme for assessment of crisp quality depending on colour (L-value) and ranges from 10 (highest) to 1 (lowest) quality:

Score	L-value	Score	L-value
10	> 69.74	5	57.15 – 58.50
9.5	68.54 – 69.74	4.5	55.89 – 57.14
9	67.23 – 68.53	4	54.61 – 55.88
8.5	66.03 – 67.22	3.5	53.44 – 54.63
8	64.78 – 66.02	3	52.03 – 53.43
7.5	63.47 – 64.77	2.5	50.77 – 52.02
7	62.22 – 63.46	2	49.52 – 50.76
6.5	61.02 – 62.21	1.5	48.26 – 49.51
6	59.82 – 61.01	1	< 48.26
5.5	58.51 – 59.81		

Cultivar and storage

In Exp. 3, the response of crisp lightness to storage depended on the cultivar (Table 4.5-c). Average crips colour values decreased from 69.2 to 65.9 in 2003 and from 68.9 to 55.1 in 2004, respectively. Consistently, the decrease of the L-values due to storage was more pronounced for cvs Carmona and Delikat, compared with Marlen and Saturna (Table 4.9-c).

4.4 Discussion

The potato processing industry requires tubers with a high DM concentration. In Germany, the lower limit for crisps is usually 22%, while 19-23% is the optimum range for French fries (Putz and Haase 1998; Böhm 2003). High DM concentrations result in higher yields of crisps and reduced crisp oil concentration (Lulai and Orr 1979). In the present study, mineral K application reduced DM concentrations in tubers (Table 4.6), which has also been observed in other studies (Schippers 1968; Rogozínska and Pinska 1991, Westermann et al. 1994a, Allison et al. 2001; Veerman 2001) and may be explained by the increased K uptake and concentration of tubers (Haase et al. 2007a).

In previous studies, increased N supply by means of mineral (O'Beirne and Cassidy 1990) or organic (Thybo et al. 2001) N fertilization decreased the DM concentration of tubers, which was assumed to be a result of postponing maturation (Hope et al. 1960). The marked decrease in tuber DM concentration after cattle manure in 2004 and after combined K (potassium sulphate) and N (horn grits) fertilization in both seasons (Table 4.6-a) may be explained by the appreciable tuber fresh yield response in that season (Haase et al., 2007a), i.e. a dilution effect. However, in the case of cattle manure, this particular yield response was considered to be the result of K rather than N (Haase et al. 2007a). The very dry growing season 2003 certainly retarded N mineralization from cattle manure. Previous studies on fertilization with cattle manure and the present experiment also showed that the yield response from cattle manure cannot be foreseen (Stein-Bachinger and Werner 1997; Neuhoff and Köpke 2002) and, thus, the response of tuber DM concentration is very difficult to predict.

Tuber DM concentrations were consistently lower when potatoes were cultivated after peas (Table 4.6-b) - probably as a consequence of the increased N supply measured after peas (Haase et al. 2007b). Pre-sprouting proved to be an efficient instrument to increase tuber DM concentrations, especially in the growing season with a high incidence of *P. infestans* (2004). This was probably due to the advanced crop development and translocation of assimilates from the canopy into the tubers (Haase et al. 2007b). However, the impact of late blight could not be exactly quantified as no control plots with chemical control were considered in the field experiments. The warm and dry weather conditions may have been a reason for the higher DM concentrations observed in the growing season of 2003 in two of three experiments (cf. Kolbe 1990). Apart from climatic conditions, tuber DM concentration has been reported to be markedly influenced by cultivar choice (Stanley and Jewell 1989). This is supported by the results presented here (Tables 4.4 and 4.6).

A cultivar-specific dry matter concentration (range) for cvs Agria and Marlen was estimated by Hebeisen et al. (2005) for conditions of conventional potato cropping. Since these estimations of a cultivar-specific DM concentration were consistently exceeded by both cultivars in the present study, it may be assumed that under conditions of organic farming tubers may be expected to have relatively higher DM concentrations than under conventional cultivation. The lower N supply in organic farming systems (Scow et al. 1998) may be held responsible for this phenomenon. This is confirmed by Roinila et al. (2003) who compared conventional high mineral N-fertilization with organic potato crop nutrition. Low N availability and thereby relatively higher tuber DM concentrations may more than compensate for the shorter period of STOR available for tuber DM accumulation due to premature senescence caused by late blight and thereby make it possible to achieve the desired tuber DM concentrations for processing.

The consistent increase in tuber DM concentrations during storage (Exps 1 and 2) suggests that losses of water due to transpiration were higher than the losses of DM by respiration. Kolbe et al (1995) showed that tubers from plants receiving high N have a relatively low DM concentration after storage at 4 °C as compared to after harvest. In contrast, no significant interaction between N supply (fertilization in Exp. 1 and preceding crop in Exp. 2) and STOR of assessment (at harvest or after storage) occurred in our experiments (Table 4.5). In Exp. 3, nine (2003), and six (2004) out of ten cultivars had a tuber DM concentration of 3% (absolute) above the recommended minimum of 22%. Overall, results suggest that tubers from organic potato cropping may be expected to have sufficiently high tuber DM concentrations for processing into either French fries or crisps. Similarly to conventional farming, weather conditions, and in organic potato cropping also the incidence of late blight make the level of tuber DM concentration difficult to predict. Hence, data reflect the findings of Veerman et al. (2002) that interactions between N application and year may occur and that they are probably due to weather conditions and soil conditions that affect N mineralization. Even though significant interactions between fertilization and cultivar or year, respectively, were established, it may be concluded from the three experiments that the contribution of N- and K- fertilization to variation in tuber DM may be rather small compared with the effect of cultivar and the year.

According to Roe and Faulks (1991), the reducing sugar concentration represents the most important factor governing product colour. Roe et al. (1990) quantified the role of reducing sugars and amino acids, and their experiments revealed that around

90% of the variation could be accounted for by variation in the sugars alone. Several studies gave evidence that high N-application rates (> 150 kg N ha^{-1}) can considerably affect (increase or decrease) reducing sugar concentrations (Swiniarski and Ladenberger 1970; Stricker 1975; Roe et al. 1990; Kolbe et al. 1995). Data on soil mineralized N at crop emergence (Haase et al. 2007a,b) indicate that a comparatively very high supply of available N will usually not be achieved in organic potato cropping. This is probably the reason why no significant response of reducing sugars to preceding cropping and fertilization was established

(Table 4.5-a,b). Besides, Stricker (1975) concluded from mineral N-fertilization experiments that the sugar concentration is influenced by N supply to such a limited extent that no detrimental effect on suitability for processing is likely.

The fact that no responses of glucose and fructose (or sucrose; data not shown) concentrations to fertilization strategy (N and/or K) were detected in our experiments (Table 5-a) may also be due to the relatively low N application rate in Exp. 2. In a study by Westermann et al. (1994) mineral K application slightly decreased tuber reducing sugar accumulation. Moll (1967) found increasing increments of K reduced reducing sugar concentrations. In accordance with Stanley and Jewell (1989), we observed no significant correlation between reducing sugars and the rate of potassium.

In Exp. 1, no interaction between nutrient supply (fertilization in Exp. 1, preceding crop in Exp. 2) and storage in terms of tuber sugar accumulation was established. In contrast, Kolbe et al. (1995) found that glucose and fructose accumulation throughout storage was increased by high N-fertilizer rates when compared with no N-fertilization. It is suggested that the relatively low N supply and/or comparatively small differentiation between treatments in the fertilization trial (Haase et al. 2007a) may be the reason for the insignificant interaction of crop N nutrition and storage.

Significant interaction between year and storage resulted in a high variability in tuber reducing sugar concentrations (Table 4.4). In Exps 1 and 2, tubers of cv. Marlen (reference cultivar for crisps) showed reducing sugar concentrations that were below the threshold of 1.5 g kg^{-1} FW (Putz 2004) (Table 4.7-a and -b). According to Putz (2004), the maximum concentration of tuber reducing sugars to be tolerated for French fries is 2.5 g kg^{-1} FW. Grassert et al. (1984) stated that high temperature and low levels of precipitation during the growing period produced low reducing sugar concentrations. After the warm and dry summer in 2003, the reducing sugar level in tubers of cv. Agria (reference cultivar for French fries) was minute. Accordingly, in all experiments, reducing sugar concentration of all cultivars was very low in that year after harvest, but also after storage compared with 2004.

Storage led to a marked increase in reducing sugar concentrations in the season with a profound incidence of late blight (2004). Results also show that the development of reducing sugar levels cannot necessarily be foreseen from the initial reducing sugar level at harvest. Sugar accumulations during storage have been shown to be mainly cultivar-specific (Iritani and Weller 1977). While the two maincrop cvs Agria and Marlen did not differ markedly in terms of reducing sugar enrichment in Exps 1 and 2 (Table 4.7-a,b), there was a large variability depending on cultivar in Exp. 3. Moreover, at harvest, almost all cultivars in Exp. 3 had reducing sugar concentrations that were below the thresholds for processing into either French fries or crisps (Table 4.7-c). The marked increase due to storage for very early and early cultivars suggests that reducing sugar accumulation may strongly depend on maturity type. Throughout the experiments, results confirmed previous research which gave evidence that the individual growing season has a tremendous impact on the initial level as well as the accumulation of reducing sugars during storage (Kolbe 1990, Putz and Lindhauer 1994).

The results also support other investigations that showed that the cultivar has a very marked impact on reducing sugar concentrations (Stricker 1975; Stanley and Jewell 1989) and that the rate of sugar accumulation during storage in a certain genotype depends on the season (Grassert et al. 1984), whereas the effect of N and K supply and seed tuber preparation may be considered to be small (Putz 2004).

Over the two experimental growing seasons, there was no clear tendency of any fertilization strategy to be favourable for achieving high French fry quality panel scores (Table 4.8-a). In contrast, Rogozińska and Pińska (1991) reported that high levels of N or K both reduced crisp and French fry quality scores. The fertilization trial implies that the largest impact on colour, texture, taste and quality score of French fries is exerted by storage. Colour and quality score were the parameters that consistently responded to storage, with a deterioration of colour and a lower quality score. Texture is known to deteriorate when a certain, yet undefined tuber DM concentration is exceeded (Putz and Haase 1998). Even though a consistent negative response of tuber DM concentration to fertilization was established, quality of French fries was not affected, which suggests that even the highest DM concentrations - as measured in tubers from zero fertilization plots - were at a level that did not endanger texture of French fries. Overall, the impact of the year was never significant, which suggests that French fry colour of organic raw stock is a relatively stable quality attribute, keeping in mind that results are derived only from two experimental seasons.

The medium-early cv. Agria (Exps 1-3) and medium-late cv. Marena (Exp. 3) proved to be well suited for conditions of organic farming. Even in 2004 - the season with marked quality losses due to storage - the quality score of these cultivars did not fall below the threshold of 3.5 (Table 4.8-c). However, none of the very early or early cultivars except cv. Velox could conserve the high quality scores given for harvest 2003 over the 4-month storage period. For the other cultivars tested, whether or not a cultivar could be considered suitable for processing depended on the year or the STOR of processing.

The alfalfa-grass/clover preceding crop caused unfavourable changes in fry colour (Exp. 2). As a consequence, other leguminous preceding crops such as peas should be preferred, because they increase marketable tuber yield (Haase et al. 2007b) without impairing quality of French fries (Table 4.8-b). However, the compound quality score was not influenced by preceding crop, probably due to the rather low weighting of colour (2-fold) within the quality score, as compared to texture (3-fold) or taste (5-fold). A consistent positive response of French fry colour to pre-sprouting was found. Usually, pre-sprouting would be expected to promote early maturation of progeny tubers (Karalus and Rauber 1997) and thereby reduce tuber reducing sugar concentrations (Hope et al. 1960). In fact, reducing sugar concentrations in cv. Agria after storage of tubers from harvest 2004 were reduced by pre-sprouting by 23%. As a consequence, the effect of pre-sprouting can probably be expected to be particularly strong in growing seasons shortened by a high incidence of late blight. Similar to reducing sugar concentrations in tubers, the final product quality was obviously much more influenced by growing season, storage and cultivar than by agronomic measures such as preceding crop, pre-sprouting or fertilization.

Likewise, French fry colour, crisp lightness - expressed as the L-value - was not affected significantly by fertilization (Table 4.5-a). Other studies, however, give evidence that K fertilization may lead to lighter crisp colour (Wilcox 1961; Murphy and Goven 1966; Herlihy and Carroll 1969; Sharma and Arora 1988; Chapman et al. 1992). Preceding crop affected crisp lightness (Table 4.5-b), as winter wheat consistently caused higher L-values than the other preceding crops (Table 4.9-b). The reduction of L-values caused by the leguminous preceding crops, especially alfalfa-grass/clover was probably due to the increased N supply (Rogozińska and Pińska 1991). However, average L-values were still so high that preceding crop seems not to have any relevance to marketability of crisps. At harvest in both seasons and after storage of the 2003 harvest tubers, crisps of cv. Marlen met very high quality standards (L-value > 69.7) in the three experiments presented (Table 4.9). Besides, with cultivars such as Marlen and Saturna, storage does not necessarily deteriorate crisp colour to an extent that saleability would be endangered (Table 4.9-c).

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5 Summarising discussion

The present study was carried out to evaluate the impact of agronomical measures intrinsic to organic potato cropping systems on crop growth, N and K nutrition, total and size-graded tuber yield in potatoes destined for processing into either French fries or crisps and the quality of the finished product at harvest and after storage.
For this purpose, three field experiments, described in chapters 2 to 4, were conducted between 2003 and 2004 (except Exp. 1: 2002-2004) in order to determine treatment effects of preceding crop, pre-sprouting, N and K fertilization, cultivar choice, and the growing season on the abovementioned parameters.

It is usually assumed that – beside late blight (*Phytophthora infestans)* – N is the most important cause of the high fluctuations in organic potato tuber yield. However, recent studies have indicated that the effects of late blight on yield in organic farming are often overestimated (Finckh et al., 2006).
The level of mineralized N in soil at potato crop emergence provides valuable information on the soil's status of available N for several reasons: Prior to emergence of the crop, the mother tuber supplies the growing plant with nutrients (Kolbe and Stephan-Beckmann, 1997). Former leaching losses of nitrate into deeper soil profiles are taken into account. Moreover, under the given climatic conditions, differences in N-mineralization between years due to weather conditions in spring may best be reflected around crop emergence.
However, soil NO_3-N concentration in May does not indicate whether considerable amounts of plant-available N (here: NO_3-N) can be expected to be mineralized from organic matter within the first half of the growing season when N demand of the crop is highest. In the two field experiments where it was assessed (chapter 2 and 3), the dynamics of soil available NO_3-N followed a consistent pattern: After a spring break at crop emergence, soil content of NO_3-N gradually declined throughout June and July and did not rise again until just before harvest of the potato crop. This observation was fully consistent with the findings of other authors (Heß, 1995; Wheatley and Ritz, 1995; Walther et al., 1996; Stein-Bachinger and Werner, 1997; Zihlmann et al., 2000). Moreover, results give evidence that the level of NO_3-N in 0-60 cm soil at potato crop emergence is mainly determined by the preceding crop, but also environmental conditions in the pre-cropping season. The N supply by crop emergence could be consistently increased when peas preceded potatoes in crop rotation as compared with cereals (chapter 2). In comparison, the short-term alfalfa/grass-clover ley appeared too sensitive to unfavourable environmental

conditions (e.g. drought) in the preceding cropping season (e.g. drought), and its efficiency in terms of N supply may therefore be hard to predict. Yet, other researchers found that 2-year leys do not necessarily provide larger amounts of N in the year after incorporation than 1-year leys, which was assumed to be due to the higher C/N ratio, or a higher percentage of grass in longer-term leys (Pommer and Mayr, 2003). In accordance with the findings of other researchers, it became evident that it is difficult to predict the actual amount of N fixed by legumes, as this depends on many factors, like the legume species and cultivar, the portion of legume in the ley, management, weather conditions and the age of the ley (Spiertz and Sibma, 1986; Ledgard and Steele, 1992; Johnston et al., 1994; Kristensen et al., 1995; Schmidt et al., 1999). STOR of incorporation, grazing intensity and sward composition may also play an important role in determining the quantity and pattern of N release following grass-clover ley incorporation (Heß, 1990; Watson et al., 2002; Djurhuus and Olsen, 1997; Hu et al., 1997; Rayns et al., 2000; Davies et al., 2001). When grass/clover residues were incorporated in late winter instead of autumn, as in the case of the present study, significant yield increases of organically cultivated potatoes were reported by Schmidtke et al. (1998).

Canopy DM and N uptake until the end of July reflected the different N status at crop emergence rather well, yet experiments indicated that a high N supply, causing higher N uptake of the canopy (leaves and stems), does not necessarily result in increasing tuber yields. Legumes consistently gave lower N utilization efficiency compared with cereals. This confirms that an increasing N recovery by canopies until the end of July may bear the risk that – subsequently – N cannot be used for tuber yield formation. The term “N utilization efficiency” – here defined as the final fresh matter tuber yield (t ha^{-1}) per kg N taken up by the whole crop until the end of July – was found to be a helpful device for assessing the capacity of cultivars to use the limited N efficiently. Another striking finding from the present work is that response of different cultivars in terms of DM accumulation in aboveground biomass may not be consistent for different levels of N supply. Accordingly, organic potato growers should choose cultivars that accumulate DM in tubers at a given N supply efficiently.

Pre-sprouting advanced aboveground crop growth significantly by shortening pre-emergence development. Data show that pre-sprouting may improve N utilization efficiency and this was found to be due to an advanced translocation of tuber DM from canopy into tubers, expressed as a ower canopy/tuber DM ratio at the end of July. The effect can be expected to be even more marked in seasons distinguished by late blight epidemics.

Pre-sprouting consistently increased total tuber FM yield, independently of preceding crop, cultivar or STOR of yield assessment only in one year (2003). However, total tuber FM yield alone does not indicate whether potato cropping is economically sound, since only certain tuber size-grades are marketable. Pre-sprouting was shown to promote both tuber DM yields (as a result of increasing tuber DM concentration and FM tuber yields) by the end of July and final tuber size-graded yields relevant for processing.

Besides, the portion of undersized tubers (<40 mm for crisps; <35 mm for French fries) was reduced initially, but the response became weaker as the growing season proceeds. The positive response was due to the increase in larger tubers (>65 mm for crisps; >50 mm for French fries) and average tuber weight, while tuber density was hardly affected. Tubers graded >65 mm are not suitable for crisps processing. It was shown that farmers can reduce the risk of high portions of oversized tubers (for crisps: >65 mm) rendered by pre-sprouting when a cultivar with a genetically determined medium number of tubers is chosen. Overall, the positive response of total and marketable tuber yields to pre-sprouting may be explained by a higher average tuber weight, and thereby a beneficial distribution of tuber size toward larger tubers.

While the response of total tuber DM yield by the end of July was mainly due to pre-sprouting and cultivar, rather than N supply (preceding crop), final tuber FM yield was affected significantly by both, preceding crop and pre-sprouting. However, it could be demonstrated that the increase of tuber FM yield, average tuber weight and marketable tuber yield due to pre-sprouting may be compensated by crops not pre-sprouted when the growing season proceeds undisturbed by late blight epidemics. Hence, in a regular potato growing season with more or less severe late blight epidemics, the positive effect of pre-sprouting on organic potato tuber yield cannot be overestimated.

Beside crop rotation, the use of organic amendments, such as green manure or cattle manure, may be an alternative means for crop nutrition (Köpke, 1995; Schmidt et al., 1999; Stein-Bachinger and Werner, 1997). Higher soil organic matter contents and availability of nutrients, better soil structure, increasing yield potential and nutrient uptake are some of the long-term effects of organic fertilization (Sommerfeldt et al., 1988; Clark et al., 1998; Mäder et al., 2002). Cattle manure was found to have a high variability in chemical composition over the years, as was also stated by others for farmyard manure from organic holdings (Piorr et al., 1990; Dewes and Hünsche, 1998; Shepherd et al., 2002). The experiments showed the low potential of cattle manure to increase plant available N and tuber N uptake. It could be shown that the positive yield response to cattle manure established in one of three years was due to K rather than N. Results showed that tuber K uptake and concentration can be expected to be increased equally by cattle manure and mineral K application. Hence, in the short-term, cattle manure may serve as a K rather than as an N source. Moreover, the relatively high K concentration measured in tubers from unfertilized control plots suggests a high potential of loamy sand to provide K from its reserves not accounted for in the soil analysis commonly used.

Results gave evidence that an increase in soil available NO_3-N can best be accomplished by readily available N sources like horn grits. Data confirm that sole N (horn grits) or K (potassium sulphate) application does not provide a nutritive regime favourable for increased marketable tuber yield (Herlihy and Carroll, 1969). Overall, it may be stated that a combined application of a mineral K and an organic N source most reliably causes increasing tuber yields, both total and size-graded for processing. In contrast, seasonal influences such as preceding crop and weather conditions obviously make the response of tuber yield to cattle manure application hard to predict. The results show that in years without late blight, or with early, yet moderate late blight epidemics, soil amendments with fertilizers acceptable in organic farming may improve marketable yields for the crisps industry and thereby increase financial returns for the organic farmer.

The cultivar was observed to have a profound impact on tuber size distribution, less so for marketable crisps tuber size-grades (40-65 mm), but on the larger tuber yields required for the French fry industry. Results indicate that the effect of the cultivar, preceding crop, and the growing season (water supply, occurrence of late blight) may have a greater impact upon the portion of large tubers within marketable yield than fertilization. In order to allow a better predictability of size-graded yield response, cultivars have to be chosen carefully, since the genetically determined number of tubers initiated is closely and negatively related to the average tuber weight, i.e. tuber sizes and their portions within total tuber yield that can be reached under conditions of limited N supply.

Cultivars with a profound dormancy and medium-late tuber initiation such as cv. Agria can reach their full yield potential only in seasons not disturbed by late blight. Similarly, DM yield as a function of FM yield and DM concentration is mainly determined by the length of the growing seasons. Cultivar was shown to have a much more marked effect on tuber DM concentration, which makes choice of cultivar *the* essential tool in cultivation of potatoes for processing.

From chapter 4 it can be concluded that the most important quality attributes for potatoes destined for processing, namely tuber DM and reducing sugar concentration, are markedly affected by the cultivar used. At the same STOR, data showed that the individual season has a marked impact upon the level of these two parameters, especially after storage. Yet, the high tuber DM concentrations result in higher yields of crisps and reduced crisp oil concentration (Lulai and Orr, 1979). High mineral N rates reduce DM concentration considerably (O'Beirne and Cassidy, 1990; Ojala et al., 1990; Westermann et al., 1994). Accordingly, DM concentration of progeny tubers was reduced when cultivated after peas, probably due to the increased supply of available N. It was also reduced by fertilization with horn grits, the organic N source which proved to be far more readily available than cattle manure, the effect being even more pronounced when horn grits were applied along with mineral K.

Yet, the high tuber DM concentrations found in the experiments can probably be attributed to the relatively low N supply given under conditions of organic farming. Nevertheless, the presented experiments show that tuber DM accumulation may be impaired in growing seasons in which late blight is prevalent. Since N mineralization from cattle manure is difficult to predict, an increase in yield and a consequent decrease of DM (dilution effect) is not to be expected. Even though a negative response of tuber DM concentration was measured in tubers from the unfertilized control plots, quality of French fries was not affected. This indicates that even the highest DM concentrations – as measured in tubers from zero-fertilization plots – were at a level that does not endanger texture of French fries.

Seed-tuber preparation by pre-sprouting increased tuber DM. This was attributed to the advanced crop development and translocation of assimilates from the canopy into the tubers. Beside climatic conditions, cultivar has a marked effect on tuber DM (Stanley and Jewell, 1989). In fact, cultivar had a significant effect in all three experiments. During storage, DM increased significantly. Changes in DM concentration during storage were attributed to increasing increments of N rates up to a very high N supply by Kolbe et al. (1995). In contrast to this, fertilization did not interact with storage, which is probably due to the limited ranges of N and/or K supply that were established in the experiments (chapters 2 and 3).

The comparatively low supply of available N at crop emergence is probably the reason why no significant response of reducing sugars to preceding crop and fertilization was established. Stricker (1975) concluded from mineral N fertilization experiments that the sugar concentration is influenced to such a limited extent that no detrimental effect on suitability for processing is likely.

The interaction of year and storage was mostly responsible for variability in tuber reducing sugar concentrations. In two of three experiments, tubers of cv. Marlen showed low reducing sugar concentrations that were below the threshold of
1.5 g kg^{-1} FW only at harvest and in one year (Putz 2004). In contrast, storage led to a marked increase in reducing sugar concentration in the season with a profound incidence of late blight. Results also show that this development cannot necessarily be foreseen from the initial reducing sugar level at harvest. Sugar accumulations during storage have been shown to be mainly cultivar-specific (Iritani and Weller, 1977). While the two maincrop cvs Agria and Marlen did not differ markedly in terms of reducing sugar enrichment, there was a large variability in reducing sugar concentration depending on cultivar. At harvest, all cultivars had reducing sugar concentrations that were below the thresholds for processing into either French fries or crisps. The marked increase due to storage for very early and early cultivars suggests that reducing sugar accumulation may strongly depend on maturity type. Throughout the experiments, results confirmed previous research which gave evidence that the individual growing season has a tremendous impact on the initial level as well as the accumulation of reducing sugars during storage (Kolbe, 1990; Putz and Lindhauer, 1994).

The fertilization trial implies that the largest impact on colour, texture, taste and quality score of French fries is exerted by storage. Colour and quality score were the parameters that consistently responded to storage, with a deterioration of colour and a lower quality score. Overall, the impact of the year was never significant, which suggests that French fry colour of organic tubers is a relatively stable quality attribute, taking into account that results are derived only from two experimental seasons.

The medium-early cv. Agria and medium-late cv. Marena proved to be well suited for conditions of organic farming. Even in the season with marked quality losses due to storage, the quality score of these cultivars did not fall below the threshold of 3.5. The compound quality score was not influenced by preceding crop, probably due to the rather low weighting of colour (two-fold) within the quality score, as compared to texture (3-fold) or taste (5-fold). Since the alfalfa-grass/clover pre-crop caused unfavourable changes in fry colour, other leguminous preceding crops such as peas that increase marketable tuber yield without impairing quality of French fries should be preferred.

A consistent positive response of French fry colour to pre-sprouting was found. In fact, reducing sugar concentration after storage was reduced by means of pre-sprouting for cv. Agria in the season with a high incidence of late blight. Overall and similar to reducing sugar concentration in tubers, the final product quality is clearly influenced much more strongly by growing season, storage and cultivar than by agronomical measures such as preceding crop, pre-sprouting or fertilization.

The reduction of lightness of crisps (expressed as L-values) caused by both leguminous preceding crops was probably due to their increased N supply (Rogozínska and Pinska, 1991). Average L-values, however, were still so high that the choice of preceding crops seems not to be relevant in terms of marketability of crisps. At harvest in both seasons and after storage in one year, crisps of cv. Marlen met highest quality standards in the three experiments. Besides, with cultivars such as Marlen and Saturna, storage does not necessarily deteriorate crisp colour to an extent that saleability would be endangered.

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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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