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Tarek Abd El-Aziz Wahba Shalaby

Genetical and nutritional influences on the spear quality of white asparagus (*Asparagus officinalis* L.)

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TABLE OF CONTENTS

List of Figures

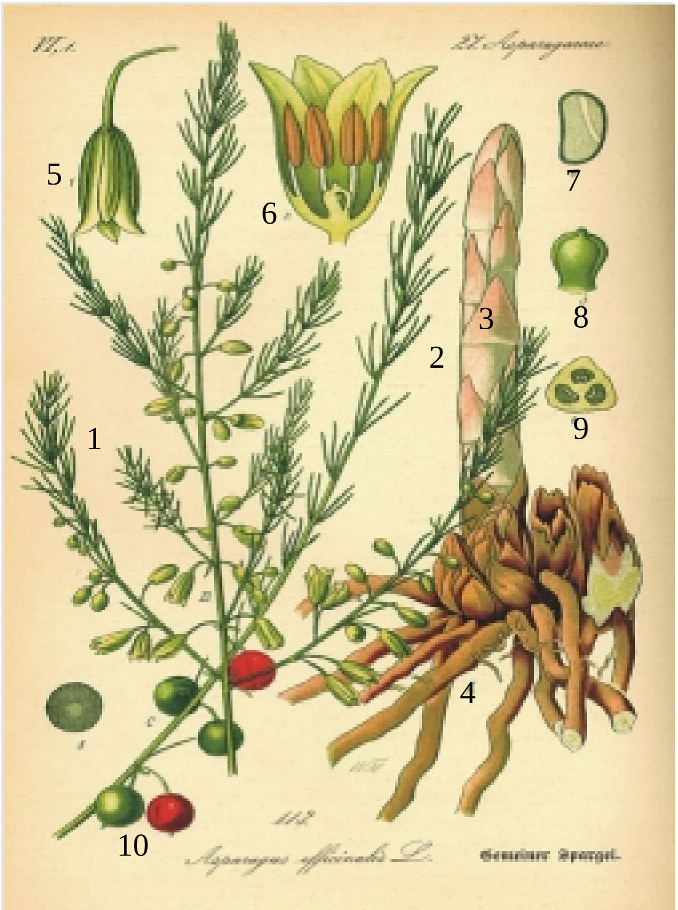
LIST OF TABLES

1. INTRODUCTION

Asparagus (*Asparagus officinalis* L.) is a plant related to the East Mediterranean vegetation (Meusel et al., 1965). The gene center of asparagus is the orient and the eastern parts of the Mediterranean. Asparagus was first mentioned as a vegetable in the documents of a French monastery in the eleventh century and the first asparagus beds were established in Germany in the vicinity of Stuttgart (Reuther, 1984). Blanching of asparagus was introduced by the Dutch at the beginning of the nineteenth century (Reuther, 1984) .

Asparagus (2n = 2x = 20 chromosomes), a monocotyledon of the *Liliaceae* family, is a dioecious, perennial species, which is productive for at least 10 years. Every spring young stems, known as spears, emerge through the ground. They represent the edible part of the plant and are collected daily over a period of about two months (Dore, 1990). After the harvest period the stems grow and develop "branches" covered with stem like cladophylls, while the leaves are reduced to small scales along the stems (Fig.1-1) and the fruit is a red berry containing black seeds. In autumn, carbohydrates and nutrients are accumulated in the storage roots. The perennial part of the plant is the crown, which has a rhizome-like structure and which consists of buds and storage roots together with rootlets for uptake of water and nutrients. The plant has a rest period during winter, except in warm climates where it grows all year long (Dore, 1990).

White asparagus (*Asparagus officinalis* L.) is an important vegetable crop in Germany. Asparagus covers a production area of about 15,000 hectares with annual spears production approaching 55,000 tons with a total value of more than 150 million Euro (Anon, 2003). White asparagus and green asparagus are the same species. The difference between both plants is that white asparagus is harvested before emergence of spears above ground and exposed to sunlight and the green crop after emergence (Makus and Gonzalez, 1991).



1 Asparagus fern
2 Asparagus spear (edible part)
3 Asparagus leaf
4 Asparagus crown with buds and flashy roots
5 Asparagus flower
6 Asparagus flower cut vertically
7 Asparagus seed cut vertically
8 Asparagus ovary
9 Asparagus transverse section of ovary
10 Asparagus fruits

Fig. 1-1: Morphology of asparagus plant (Kurt Stübers online library)
http://www.biologie.uni-hamburg.de/b-online/thome/band1/tafel_115.html

1.1 Nutritional value of asparagus and significance of S-containing compounds

Asparagus is a nutritional "all star": it is low in calories with virtually no fat and very low in sodium and contains more glutathione (26 - 40 mg 100 g^{-1} fresh weight) than any other fruits and vegetables (Saito et al., 2000; Anon, 2001). Light cooking of asparagus preserves the glutathione content while prolonged cooking or canning (like with any other fruit or vegetable) leads to degradation of glutathione (Anon, 2001). Asparagus is a medicinal plant which has a diuretic effect and because of its high glutathione content it was identified as being beneficial for humans with heart problems (Leung and Foster, 1996).

Table 1-1 shows the mean, minimum and maximum content of major compounds and nutrients in fresh asparagus spears (Souci et al., 2000).

Today, fruits and vegetables enjoy much attention as part of a healthy diet. Aside from being low in fat, fruits and vegetables are rich sources of antioxidants such as glutathione, vitamin C and vitamin E and their consumption is supposed to slow the development of both cancer and heart disease (Richie, 1992). Food sources of these substances also tend to be rich in dietary fiber which is another positive criteria for a balanced diet (Marwick, 1995).

Table 1-1: Mean, minimum and maximum content of major constituents and nutrients in 100 g of fresh asparagus spears (edible parts).

Constituents	**Unit**	**Mean**	**Minimum**	**Maximum**
Water	%	93.5	93.0	94.0
Total protein	%	1.91	1.5	2.2
Fat	%	0.16	0.1	0.21
Carbohydrates	%	2.04	--	--
Total dietary fiber	%	1.31	1.27	1.47
Total nitrogen	%	0.31	--	--
Phosphorus	mg	45	35	62
Potassium	mg	202	145	280
Sulfur	mg	32	--	--
Calcium	mg	26	19	26
Magnesium	mg	17	8	22
Iron	µg	684	442	1520
Zinc	µg	397	200	800
Manganese	µg	103	100	300
Copper	µg	153	70	160
Vitamin C	mg	20	5	38
Vitamin A	µg	30	--	--
Vitamin E	mg	2	--	--
Glutathione	mg	26	10	45

(Source: Souci et al., 2000 and Saito et al., 2000)

Vitamin C (ascorbic acid) is known since long as a powerful bio-active compound in the human body. It decreases duration and severity of the common cold (Hamila, 1992). But now vitamin C is increasingly recognized as an agent with broad biological functions, amongst others against cancer (Block, 1991). Vitamin C is an antioxidant that may help in preventing cancer, coronary artery disease, and arthritis, and reducing the effects of aging (Block, 1991). Additionally, vitamin C enables iron absorption and is involved in the metabolism of folate and proteins. It enhances the efficacy of another antioxidant, vitamin E, which has recently been shown to reduce heart disease (Block, 1991). Asparagus has a high ascorbic acid content, which ranges from 20 to 38 mg 100 g^{-1} fresh white and green asparagus, respectively (Lai et al., 1973). Vitamin A (30 µg 100 g^{-1}) and vitamin E (2 mg 100 g^{-1}) are amply represented (Souci et al., 2000).

Certain S-containing compounds are directly responsible for the unique taste and flavor of many vegetables (Schnug, 1997). The flavor of asparagus is due to particular S compounds: besides asparagusic acid, 3-mercaptoisobutyric acid, 3- methylthioisobutyric acid, diisobutyric acid disulfide and 3-S-acetylthio-methacrylic acid were identified (Tressel et al., 1977). Significant differences of sensory characteristics were determined among 14 cultivars which indicates the genetic regulation of asparagus flavor compounds next to environmental and cultivation influences (Holberg et al., 1999).

Glutathione is a sulfur-containing antioxidant with strong anti-carcinogenic potential (Richie, 1992). It is a naturally occurring protein that protects every cell, tissue and organ from toxic free radicals. It is a tri-peptide of the three amino acids glycine, glutamic acid and cysteine. These precursors are necessary for the synthesis of glutathione in plants. Without glutathione the function of other important antioxidants such as vitamin C and E is restricted and thus the protection of the body is limited. No other antioxidant is as important to overall health as glutathione, it is the regenerator of immune cells and the most valuable detoxifying agent in the body (Petrosino, 2002). The significance of glutathione for human health relies on the following functions: glutathione acts as an anti-oxidant, it breaks down highly toxic peroxide and oxygen-rich compounds, thus preventing damages to cell membranes, genetic materials (eg. DNA), and other cell constituents. Glutathione is also part of the repair mechanism for damaged DNA (Garden-Robinson, 2001; Galen, 2000). Glutathione may bind carcinogens in the human body, promoting their natural excretion via urine or feces (Richie, 1992). Glutathione is generally involved in the immune system of the human body (Galen, 2000). Glutathione is part of the recycling vitamin C and E from an inactive to an active status (Wardlaw, 2001).

Glutathione is available in powder and capsule form, but the powder has a tangy sour taste (Anon, 2002). Since glutathione increases the ability of the liver to process xenobiotics, there is a possibility that a regular intake of glutathione might reduce the efficiency of chemotherapy (Perlmutter, 2002). Without doubt fresh fruits and vegetables are the best source of glutathione for the human health. Rich sources of glutathione include asparagus, avocado and watermelon which contain between 28 – 35 mg glutathione 100 g^{-1} fresh weight (Pressman, 1997; Saito et al., 2000).

1.2 Influence of genotype and growth conditions on the nutritional quality of asparagus

Different factors such as cultivar, degree of maturity, fertilization, spear weight, harvesting date, storage conditions and industrial processing have an influence on the quality of white asparagus (Zurera et al., 2000).

The characterization of new cultivars is an important part of any asparagus improvement research program. The perennial nature of the crop and the difficulties of a quick swap of cultivars after planting makes clear that the choice of the cultivar is crucial for the successful commercial production of the crop (Nichols and Fisher, 1999). In previous studies it was shown that there are differences in spear quality among different cultivars but also annual fluctuations were observed (Poll, 1995; Paschold et al., 1996; Mullen et al., 1999). Research results from cultivar trials in New Zealand have shown that on the same site the economic yield can vary between cultivars by as much as three times in total yield and by as much as seven times in marketable yield (Nichols and Fisher, 1999).

The major difficulty involved in any asparagus cultivar trial is the extended harvest period within each growth season, and consequently high variability of quality parameters of spears and crop productivity within the years (Nichols and Fisher, 1999). Marketable yield varies from year to year depending on plant age, harvest length and prevailing weather conditions during the harvest period (Drost, 1999). Rameau and Denis (1992) studied genotype-environment interactions and these results indicate that a significant part of genotype-environment interactions in asparagus are related to low temperatures during the dormant period. The climate during this period effects the physiology of the sub-ground crown. This is important, because the yield of asparagus is a function of carbohydrate reserves in storage roots which were produced by the previous year shoots. Benson et al. (1996) tested one purple and three green asparagus cultivars. They found differences between cultivars with respect to yield and quality (spear diameter, texture and head tightness). The same results were reported by Knaflewski and Islam (1993) in Poland and Bussel et al. (1988) from experiments conducted in New Zealand.

Makus and Gonzalez (1991) found that white asparagus had a significantly lower protein content than green asparagus. The total protein content of the varieties *Jersey Continental* and *Lucullus* was 23.1% and 24.4% in mid season (Mineroamador et al., 1992). Nitrate levels were reported to be 62% and 49% higher in asparagus spears grown under black and white row covers*, respectively and both protein and nitrate levels changed over the harvest season, with maximum levels generally associated with the peak season yield in the 5th week of the harvest (Makus and Gonzalez, 1991).

The ascorbic acid content has been found to be higher in the upper segment of the spears gradually decreasing from tip to the base (Makus and Gonzalez, 1991). The tip of white and green spears contained 18% – 63% more ascorbic acid than the middle and the base segments (Makus and Gonzalez, 1991). Lai et al. (1973) reported that the ascorbic acid content ranged from 20 to 38 mg per 100 g in white and green asparagus spears.

A textural comparison between green and white asparagus was conducted on three cultivars (*Jersey Gem, Jersey General* and *Jersey Giant*) harvested during spring and summer of 1990 (Brovelli et al., 1998). Spears were analyzed for fibrousness and sensory characteristics at three different sections: tip, middle and base. Fibrousness of both green and white spears was higher in spring than in summer. White spears were more fibrous than green one and fibrousness increased from tip to base (Brovelli et al., 1998). Gast et al. (1991) found differences between seven asparagus cultivars in respect with fibrousness.

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* In Germany, clear plastics have been used principally as a soil warming technique and black row covers provided maximum yield of white asparagus. When asparagus is grown under conditions that allow spears to develop in darkness, chlorophyll is not synthesized and developing spears appear white.

Amaro et al. (1998) investigated variations in the Cu, Fe, Zn, Mn, Mg, Ca, Na, K and P content of fresh white asparagus spears in dependence on the spear segment, spear diameter and genotype. The elemental concentration increased from base to tip when cut into 10 segments with the exception of sodium. Thus in terms of minerals the spear tips have a higher nutritional value than the base parts.

1.3 Influence of the nutrient supply on the nutritional quality of asparagus

The level and timing of nitrogen application had only a small effect on the N content of asparagus (Krarup, 1991). In addition, Makus (1995) reported that the timing of N application had no effect on spear yield and pigment concentration. The same author found that an early application of 80 kg ha^{-1} N in March decreased K concentrations in white asparagus spears and the Ca content in green asparagus spears but had no significant effect on total protein content. Furthermore, fertilization with N, P and K had no significant effect on the ascorbic acid content of spears during two years of experimentation (Omran, 1998).

Brown et al. (1961) and Espejo et al. (1996) reported from field fertilizing experiments with phosphorus (P) that yield of asparagus was not affected by P fertilization. Increasing P rates had no influence on the properties of the spear, but tendentiously increased the spear diameter. Krarup (1989) and Taga (1989) found that there were no significant differences in the N, P and K contents of the spears in relation to fertilizer rates. In another study Taga (1989) found that the N and P content in the spears decreased with plant age.

Sulfur (S) is an essential element for plant growth because S is a constituent of the S-containing amino acids, cysteine and methionine. S also occurs in various plant compounds of low molecular weight, for instance secondary compounds (Anderson and McMahon, 2001). Many S containing compounds are important for plants to tackle with both biotic and abiotic stress (Haneklaus et al., 2002). S deficiency will therefore not only reduce product quality but also weaken the general stress tolerance of plants or increased susceptibility towards pests, diseases and abiotic stress (Schnug, 1990; Lamoureux and Rusness, 1993). Under conditions of S deficiency, plants can not synthesize sufficient amounts of proteins and this, in turn, means that nitrogen can accumulate in plant tissues in non-protein forms such as nitrate (Eppendorfer and Eggum, 1994; Schnug, 1997). Nitrate has a low toxicity to humans but products of nitrate reduction, however, are toxic and can lead to severe pathologies in humans. These products include nitrite and the nitroso-N compounds that are formed when nitrite interacts with other substances before or after ingestion (WHO, 1995). S deficiency promotes the accumulation of nitrate in plant tissue particularly when the N supply is high. Since vegetables are often fertilized intensively with nitrogen, the N/S balance is highly important with view to the crop quality (Schnug, 1997; Santamaria et al., 2002).

Warncke et al. (2002) reported that lime application increased the plant available Ca and Mg concentrations in the soil, but had no effect on the elemental composition of asparagus.

1.4 Influence of processing procedures on the nutritional quality of asparagus

The quality of asparagus spears is very sensitive to many environmental factors. Harvesting, handling, storage and transportation of asparagus from producer to consumer may require as much as 21 days (Drake and Lambert, 1985). Quality of the asparagus must be maintained over this period of time if consumers are to be satisfied with the product. Time in refrigerated storage can constitute most of the delay required for delivering of asparagus to either fresh or processing market. Storage greatly alleviate peak production problems (Drake and Lambert, 1985; King et al., 1986). The industrial processing such as canning, drying and freezing increases the keeping quality of fruits and vegetables. The common technological operations carried out are washing, peeling, blanching and sterilization of the spears (Amaro et al., 1997). Because it is commonly acknowledged that processing results in significant losses of nutrients, the fresh product is perceived as being more nutritious than canned or frozen products (Klein, 1987).

Lopez et al (1999) studied changes in the essential trace element (Cu, Fe, Mn and Zn) content of white asparagus spears in order to investigate the effect of industrial processing of asparagus on the mineral content and to estimate if these possible changes involve a modification of its nutritional value. The main effect was a decrease in Fe and Mn levels and an increase in the Cu and Zn content throughout the processing (Lopez et al., 1999). The varieties and thickness of the white asparagus affected the mineral content of spears during industrial processing (Lopez et al., 1999). In another study, Amaro et al. (1997) reported that all mineral elements studied showed significant changes in their levels throughout the processing stages with a decrease of the Ca and Na contents and an increase in the Mg, P and K contents. These variations were especially related to peeling of the asparagus since the loss of the spear peel may imply changes in the mineral content. The same author found that peeled spears had higher mineral contents than washed spears.

Investigations conducted by Shalaby et al. (2003) showed that the average weight loss of five asparagus cultivars stored at 4 °C after two weeks was 2.8%. The glutathione, cysteine and ascorbic acid content decreased with increasing storage time and there were significant differences among asparagus cultivars. On average, the glutathione content decreased from 20 µmol g^{-1} to 8 µmol g^{-1} in spears and cysteine from 8.5 µmol g^{-1} to 2.3 µmol g^{-1} after two weeks of storage. In another storage experiment, Lill (1980) showed that ascorbic acid was lost during storage. After two weeks the ascorbic acid content was 32% lower than initially, during the third and fourth weeks another 17% and by the end of the sixth week a further 6% of ascorbic acid was lost (Lill, 1980). Shalaby et al. (2003) reported losses in ascorbic acid of up to 47% after two weeks of storage.

Asparagus was found to be a good source of protein (>30% dry weight), containing most of the essential and non-essential amino acids (Lopez et al., 1996). Generally, the amino acid content decreased significantly with blanching and canning (Lopez et al., 1996). Green asparagus protein showed an adequate amino acid content according to FAO/WHO recommendations, and seems to contribute most of the essential amino acids, except histidine and lysine, which were actually available in limited amounts (Lopez et al., 1996).

N fertilization has become a matter of concern because of costs and possible contamination of under ground water occur if the rate is higher than the demand (Krarup et al. 2002). Nitrogen fertilization rate of asparagus varies independence on country, soil type, plant age and yield potential of the cultivar from 50 to 350 kg ha^{-1} N (Krug and Kailuweit, 1999; Krarup, 1991; Pinkau and Grutz, 1985; Flaspöhler, 1955). Carolus (1962) recommended that the N fertilizer rate can be reduced drastically since asparagus with a yield of 500 kg ha^{-1} removes only 21 kg N.

Nowadays, the awareness of consumers for the nutritional quality of vegetables has significantly increased. A high intake of vitamins, glutathione and minerals and low intake of nitrate are recommended. It was found that sulfur supply significantly increased glutathione content (De Kok et al. 1981; Schnug et al., 1995) and essential for the synthesis of proteins in plants (Kleinheinz, 1999). Nitrogen fertilization increased NO_3 content (Sorenson, 1999). Both the nitrogen and sulfur nutrition are known to affect strongly crop productivity and quality (Schnug, 1990). But there are no available studies about the influence of genotype and nitrogen and sulfur supply on the nutritional quality of asparagus. Therefore, the key objectives of this work were :

1. to evaluate the influence of genotype and growth conditions on qualitative parameters of asparagus spears in field experiments and in an extended field survey,
2. to study the influence of the sulfur supply on quality parameters of asparagus spears under field conditions,
3. to determine the influence and interaction of the nitrogen and sulfur supply on asparagus growth, yield and qualitative parameters of asparagus spears and fern, and
4. to determine the impact of nitrogen and sulfur on growth of asparagus transplants in a pot trial.

2 MATERIALS AND METHODS

2.1 Field experiments

Field experiments and the field survey were carried out at different locations, Braunschweig, Veltenhof, Gross Schwülper and Rietze (Lower Saxony), Erfurt (Thuringia) and Alt Mölln and Wiemersdorf (Schleswig-Holstein) in Germany (Fig. 2-1).

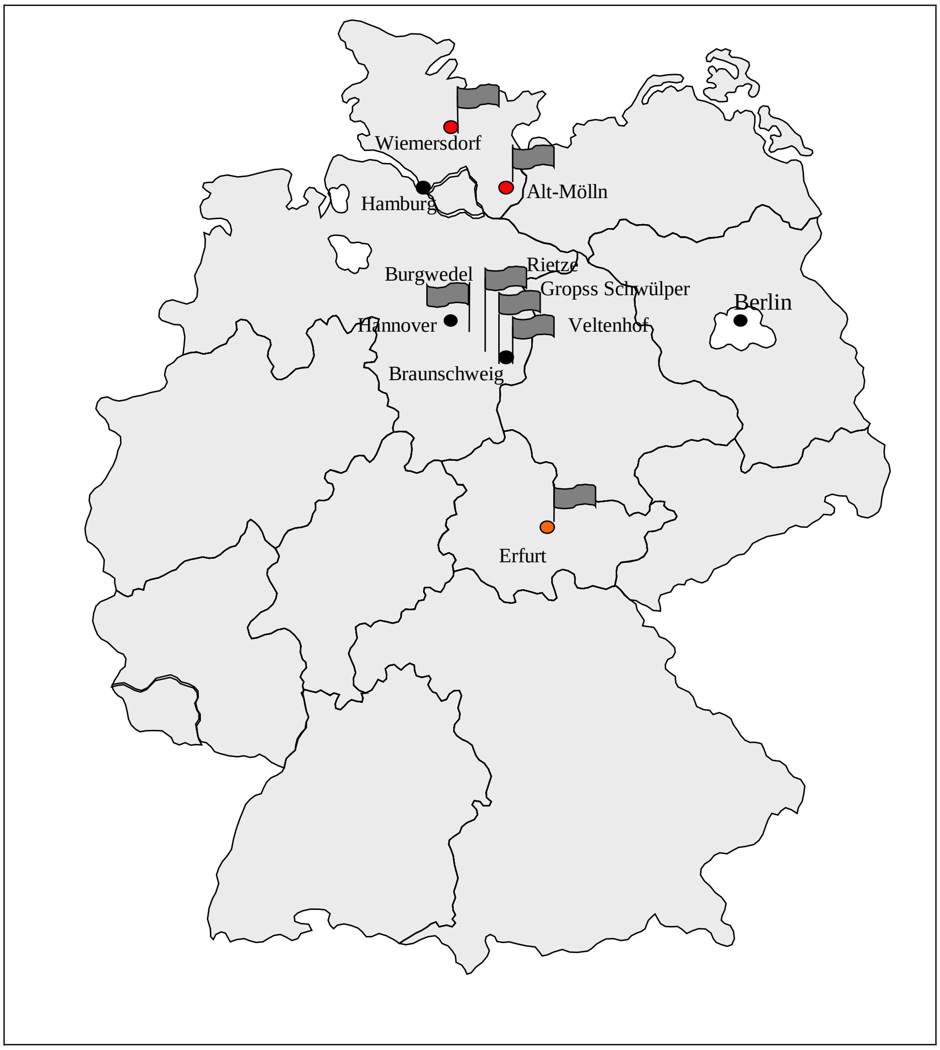

Fig. 2-1: Experimental sites of asparagus field experiments in Lower Saxony, Thuringia and Schleswig-Holstein

2.1.1 Variety field trials

Field experiments were carried out to study the effect of the genotype on the content of mineral and organic compounds of asparagus spears and fern. In 2001 grade one (16-26 mm diameter) spear samples of different asparagus cultivars and new genotypes (*Ariane, Eposs, Gijnlim, Hannibal, Ramada, Ramos, Ramses, Ranger, Rapid, Ravel, Stamm 12, Stamm 14, 17/24, 17/30* and *96012*) were taken from crop performance trials in Burgwedel (52° 37.4' N; 9° 50.2' E), Lower Saxony on 11 May and fern samples were taken on 6 September. In Wiemersdorf (53° 52.7' N; 10° 20.6' E) in Schleswig-Holstein, samples from in total five cultivars (*Boonlim, Eposs, Gijnlim, Huchels Alpha* and *Thielim*) were taken on 15 May and fern samples were taken on 7 September. Both experiments were laid out in a completely randomized design with four repetitions in Burgwedel and three repetitions in Wiemersdorf. The results of the chemical analysis of the soils in both locations is shown in table 2-1 and the horticultural characteristics of asparagus cultivars and genotypes are shown in table 2-2.

2.1.2 Field surveys

In 2000 extended field surveys were conducted in the regions of Braunschweig (52°19.0`N; 10°29.1`E) and Erfurt (51°01.4`N; 11°02`E) in order to study the influence of the cultivation region on spear quality parameters. Grade two spear samples and soil samples were taken simultaneously on 15 May from 24 production fields in the area of Braunschweig and 27 samples were collected in the region of Erfurt. The results of the chemical analysis of the soil is shown in table 2-1. Individual data of soil analytical results is given in the appendix (Table 7-1).

Table 2-1: Soil chemical parameters (topsoil, 0-30 cm) of the experimental sites in Burgwedel, Wiemersdorf, Braunschweig and Erfurt.

Site	pH	Total C (%)	Total N mg g^{-1}	N_{min}* kg ha^{-1}	S_{min}* kg ha^{-1}	Available		
						P mg kg^{-1}	K mg kg^{-1}	Mg mg kg^{-1}
Burgwedel	5.6	2.28	1.29	27.8	47.2	138	89.2	57.6
Wiemersdorf	5.9	2.36	1.01	16.0	35.6	263	118	141
Braunschweig	5.8	0.50	0.49	59.0	51.0	115	123	27.7
Erfurt	6.8	1.85	1.84	83.0	23.0	36.2	66.7	154

Braunschweig (52°19.0`N; 10°29.1`E); Erfurt (51°01.4`N; 11°02`E); Burgwedel (52° 37.4' N; 9° 50.2' E); Wiemersdorf (53° 52.7' N; 10° 20.6' E), * (0-30 cm)
Date of soil sampling : Burgwedel and Wiemersdorf: 20 August 2003, Braunschweig and Erfurt: 15 May 2000.

Table 2.2: Horticultural characteristics of the asparagus cultivars and genotypes.

Cultivar	**Horticultural characters**
Ariane	New German cultivar from Deutsche Spargelhochzuchtstation, Dieter Gast, Alt Mölln; high yield; spears have closed heads, with high fern mass.
Boonlim	Dutch cultivar, middle early cultivar with moderate yield. With increased plant number per row however relatively good quantity yields are possible. It supplies very thick spears with closed heads. Boonlim is less susceptibly to Botrytis. It can be used relatively well on area, on which asparagus was before already cultivated.
Eposs	German cultivar, early production with good yield achievement and brings predominantly medium grade with closed heads. The cultivars shows an upright summer fern with good disease tolerance against fern disease and is interesting also for the cultivation "asparagus after asparagus".
Gijnlim	Dutch cultivar, very early production, high yield, high average spear weight and spears are thick in the middle with high number from grade one, suitable to cultivate under black row covers.
Hannibal	F1 all-male hybrid cultivar, German cultivar with very good taste, spears are thick in the middle, fern is dark green and tolerant to fern diseases.
Huchels Alpha	Old German cultivar, Middle early production, male and female plants. The cultivar is long-lived and supplies many years relatively evenly high yields. Spears has a good taste and closed heads
Ramada	New German cultivar with high yield and high average spear weight and high tip qualities and high potential of yield. The good stability as well as a loose, upright summer growth of fern are characteristic.
Ramos	German cultivar with high yield and quality. The summer fern penetrated medium highly, and show a good tolerance in relation to fern diseases. Ramos supplies smooth spears with well closed heads.
Ramses	New German cultivar from Südwestdeutsche Saatzucht, Dr. H.R. Späth, Rastatt. This cultivar produces high yield, spears are thick with closed heads.
Rapid	New German cultivar from Südwestdeutsche Saatzucht, Dr. H.R. Späth, Rastatt.
Ravel	Very early new German cultivar. Ravel provides thick white spears with closed heads.
Stamm 12	New German genotype from Deutsche Spargelhochzuchtstation, Dieter Gast, Alt Mölln
Stamm 14	New German genotype from Deutsche Spargelhochzuchtstation, Dieter Gast, Alt Mölln
Theilim	Dutch cultivar, early production, high yield, good cultivar to cultivate under row covers, spears are thick in the middle with closed heads, tolerant to botrytis
St. 17/24	New genotype from Südwestdeutsche Saatzucht, Dr. H.R. Späth, Rastatt
St. 17/30	New genotype from Südwestdeutsche Saatzucht, Dr. H.R. Späth, Rastatt
St. 96012	New genotype from Südwestdeutsche Saatzucht, Dr. H.R. Späth, Rastatt

2.1.3 Sulfur response trials under field conditions

At three experimental locations close to Braunschweig (Lower Saxony) in 1999 and 2000 and in Alt-Mölln (Schleswig-Holstein) in 2001, the influence of sulfur fertilization on spear quality parameters was investigated. The result of the chemical analysis of the soils is shown in table 2-3.

Table 2-3: Results of the chemical soil analysis (topsoil, 0-30 cm) of samples taken at the experimental sites in the Braunschweig area and Alt Mölln.

Location	Year	Cultivar	pH	Total C (%)	Total N mg g^{-1}	N_{min}* kg ha^{-1}	S_{min}* kg ha^{-1}	Available P	Available K	Available Mg
								.... mg kg^{-1}.......		
Alt Mölln	2001	*Ariane*	5.7	1.1	0.82	53.8	26.1	303	147	109
Veltenhof	1998/99	*Rekord*	6.4	0.3	0.40	16.0	12.0	93.2	131	44.1
Gross Schwülper	1998/99/ 2000	*Schwetzinger Meisterschuss*	4.5	0.5	0.50	90.0	160	140	130	36.2
Rietze	1998/99/ 2000	*Huchels Alpha*	5.7	0.9	0.70	101	86.0	85.1	100	30.1

Alt Mölln (53° 19.0´ N; 10° 29.1´ E); Veltenhof (52° 18' 18.28´´ N; 10° 28' 48.23´´ E); Gross Schwülper (52° 21' 09.32´´ N; 10° 25' 09.33´´ E); Rietze (52° 25' 24.98´´ N; 10° 20' 25.51´´ E) * (0-30 cm)
Date of soil sampling : Alt Mölln: 20 August 2003, Veltenhof, Gross Schwülper and Erfurt: 17 May 1999.

Three experiments in Braunschweig at the experimental site in Veltenhof, Gross Schwülper and Rietze were carried out with three cultivars "*Rekord, Schwetzinger Meisterschuss* and *Huchels Alpha*", respectively. In every experiment, 100 kg ha^{-1} S was applied as potassium sulfate after the harvest season in 1998 (3 July) and other 100 kg in 1999 (24 June); the control treatment received no sulfur fertilization. All experiments were laid out in a complete randomized block design with three repetitions. Spear samples of *Schwetzinger Meisterschuss* grown at Gross Schwülper and *Huchels Alpha* grown at Rietze were collected on 17 May and 9 June in 1999 and on 9 June in 2000 from every replication. Spear samples of the cultivar *Rekord* grown at Veltenhof were collected on 17 May and 9 June in 1999.

In 2001 at the experimental site in Alt Mölln, (53° 19.0´ N; 10° 29.1´ E) Schleswig-Holstein, the cultivar *Ariane* was used. 100 kg ha^{-1} S was applied as elemental sulfur on 27 March and the experiment was laid out in a complete randomized block design with three repetitions. Spear samples and fern samples were taken on 15 May and 7 September, respectively.

2.2 Greenhouse Experiments

Under greenhouse conditions pot (in Mitscherlich pots) and large pot experiments were carried out in order to study the influence of sulfur and nitrogen supply on the growth of asparagus transplants in pot experiment and on spear yield and quality of the cultivar *Hannibal* grown in large pots. The layout of the experiments is summarized in table 2-4. Fig. 2-2 shows asparagus plants grown in Mitscherlich and large pots.

Seedlings of two asparagus cultivars (*Hannibal* and *Huchels Alpha*) were cultivated in "Mitscherlich" pots (one plant per pot). The experiment had a factorial design. Plants were watered in accordance to demand with distilled water. 20 weeks after start the experiment the following data were recorded for the "Mitscherlich" experiment:

1- number of shoots per plant,
2- plant height (cm),
3- shoot fresh and dry weight (g),
4- root (crown and flashy roots) fresh and dry weight (g),
5- number of flashy roots per plant,
6- number of buds per crown, and
7- chemical composition of the plant tissue (shoots and roots).

Table 2-4: Experimental design of the greenhouse experiments.

Exp	Pots	Culture media	N-fertilization	S-fertilization	Cultivars
1.	Mitscherlich	Sand (8 kg pot^{-1})	N1: 250 mg pot^{-1} N N2: 500 mg pot^{-1} N	S1: 1 mg pot^{-1} S S2: 5 mg pot^{-1} S S3: 25 mg pot^{-1} S	Seedlings of 1: *Huchels Alpha* 2: *Hannibal*
2.	Large pot	Sand (200 kg pot^{-1})	N1: 1125 mg pot^{-1} N N2: 2250 mg pot^{-1} N	S1: 75 mg pot^{-1} S S2: 225 mg pot^{-1} S S3: 450 mg pot^{-1} S	*Hannibal* (one year old crown)

Notes: N as ammonium nitrate
S as potassium sulfate; with K balance by KCl
All other nutrients were sufficiently supplied for optimum growth

In the large pots trial, one year old crowns of the cultivar *Hannibal* were planted. The fertilizers were added before the planting (19 April, 2001) by mixing them thoroughly in dissolved form with the sand. Leachates were collected and added again to the soil. The experiment was laid out in split plot design with four repetitions. Two levels of N were arranged in the main plots and three levels of S were assigned in the sub plots. The following data was recorded during two years of experimentation:

1- number of spears per plant,

2- spear fresh and dry weight per plant (g),

3- spear diameter (mm),

4- average spear weight (g),

5- plant height (cm),

6- number of main shoots, and

7- chemical composition of spears and shoots samples.

Spears were immediately shock frozen in liquid nitrogen after harvest and then freeze-dried. Annually fern samples were taken (top 30 cm) at the beginning of August and dried at 70°C in a ventilated oven until constancy of weight.

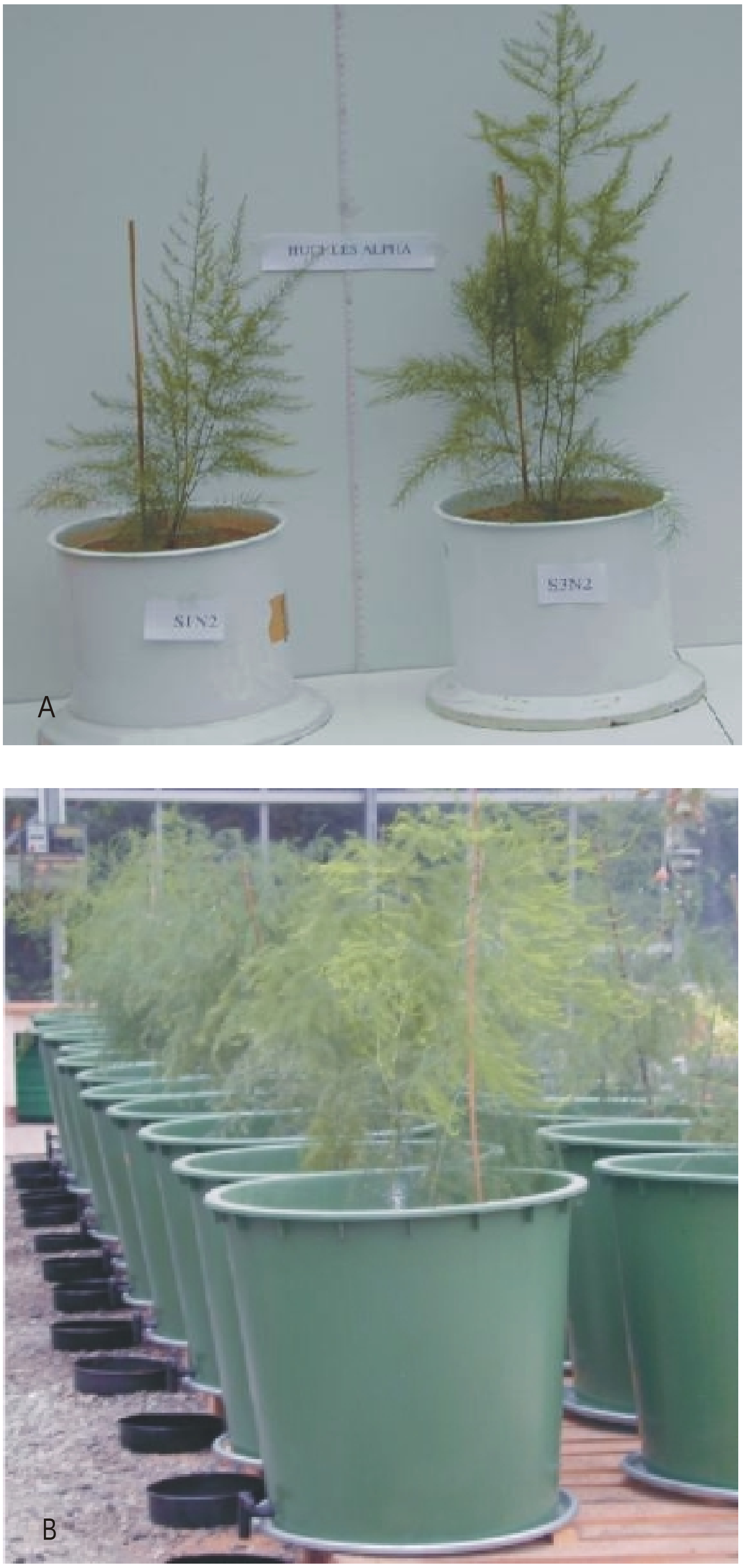

Fig. 2-2: A: Asparagus transplants of the cultivar *Huchels Alpha* grown in Mitscherlich pots (left: S1N2; right S3N2).
B: Asparagus plants of the cultivar *Hannibal* grown in large pots.

2.3 Soil analysis

Top soil samples were taken from the 0 - 30 cm layers. The samples were air-dried and sieved to a particle size < 2 mm for the chemical analysis of soils. The following methods were used:

- Soil reaction (pH) was measured potentiometerically in 0.01 m $CaCl_2$; 1:10 suspension according to Schlichting and Blume (1966).
- Total carbon was determined using the Leco Carbon determinator (EC-12 Model 752-100)
- Total N was determined by the *Kjeldahl* method.
- N_{min} was determined according to Kücke and Przemeck (1982).
- Plant available P and K were extracted by the calcium ammonium lactate (CAL) method according to Schüller (1969). P was determined colorimeterically and K by means of flame photometry.
- Plant available S was extracted in 0.025 m KCl according to Bloem (1998); SO_4-S was determined by ion chromatography.
- Plant available Mg was extracted by $CaCl_2$ according to Schachtschabel (1954) in 0.01m $CaCl_2$ solution and final determination was carried out by atomic absorption spectroscopy.

2.4 Plant analysis

2.4.1 Sample preparation

Spear samples were carefully cleaned with distilled water and cut to a length of 15 cm. Afterwards, an aliquot of the spear samples was shock frozen in liquid nitrogen and freeze-dried for the determination of glutathione and cysteine. Another aliquot of spear and fern samples was dried at 70 °C in a ventilated oven until constancy of weight and fine-ground to a particle size < 0.12 mm employing an ultra-centrifugal mill (RETSCH ZM 1).

2.4.2 Analysis of inorganic compounds

The total N content was determined by the *Kjeldahl* method. Nitrate and sulfate were extracted by de-ionized water and determined according to Kücke and Schnug (1996) and Novozamsky et al. (1986), respectively. A dry ashing procedure was applied in order to determine the total content of K, Ca, P, Mg, Cu, Fe, Mn, and Zn: the dry sample material (0.5g) was incinerated at 490 °C for 16 hours. After cooling to room temperature 10 ml 2N

HCl was added and afterwards the solution was completely evaporated on a hot plate. Then 10 ml 2N HCl was added and the solution was quantitatively transferred into 50 ml volumetric flasks, made up to volume with de-ionized water and finally filtered through filter paper (Schleicher & Schuell 593 1/2). For determination atomic absorption spectroscopy (AAS) was employed for Mg, Fe, Zn, Mn, and Cu, flame emission spectroscopy for K and Ca and colorimetery according to John (1970) for P.

S was determined by X-ray fluorescence spectroscopy according to Schnug and Haneklaus (1999): The finely ground material was mixed with HOECHST wax "C" in a ratio of 1: 4 using a magnetic stirrer, in beakers, for 5 minutes. The stirrers employed are specially designed to produce a tumbling action, which yields a homogenous mixture of sample material and wax. The amount of sample material required for the preparation of powdered parts should be in the range 0.9 – 1.1 g. The homogenate was then transferred into aluminum cups (∅ 40 mm) and compacted by means of a hydraulic press at 1.2 t cm^{-2} to a powdered part and finally was measured by X-ray fluorescence spectroscopy.
All used apparatus was calibrated by reference samples.

2.4.3 Analysis of organic compounds

Ascorbic acid: 100 g spear sample were mixed with 100 ml oxalic acid (6 %) for five minutes using an electric mixer. Afterwards, the solution was filtered and 20 ml were taken and made up to 100 ml with 3 % oxalic acid. Finally, ascorbic acid (mg 100 g^{-1}) was determined employing the 2,6-dichlorophenol indophenol visual titration method according to AOAC (1970).

The protein content was calculated on basis of the total nitrogen content using the following formula:

$$\textit{Total N content (\%) x 6.25 = total protein content (\%)}$$

Cysteine and glutathione were determined by HPLC according to Hell and Bergmann (1990). For the extraction of cysteine and glutathione, 20-30 mg of fine ground freeze-dried plant material were dissolved with 1 ml of 0.1 M HCl containing 4% PVP (Polyvidon-25) and homogenized in 1.5 ml Eppendorf cups. The samples were stored in a freezer for 15 minutes and were homogenized during this time 3 to 4 times before being centrifuged for 5 minutes at

14000 rpm at 4°C. The supernatant was transferred with a pipette into a new Eppendorf cup and again centrifuged for 3 min. at 14000 rpm. Again the supernatant was transferred into new Eppendorf cups. These extracts can be stored at –20°C for 1 year (Hell and Bergmann, 1990). DTT (DL-dithiothreitol) was added as a reducing agent prior to adding the fluorescence Bromobimane (Sigma No. B-4380).

By HPLC equipped with a fluorescence detector (480 nm) the total cysteine and glutathione was measured. Main characteristics of the HPLC are listed in table 2-5. The sample preparation for HPLC analysis has to be done in tinted Eppendorf cups (2 ml ambra) to prevent light oxidation of the samples. The total sample volume was 270 µl.

Table 2-5: Instrumental settings of the HPLC for cysteine and glutathione determination.

Column:	Nova-Pak C18, 4µm, 60Å, 4,6 x 250 mm
Flow:	1,0 ml/min
Detection:	Fluorescence detection, Excitation wavelength = 380 nm, Emission wavelength = 480 nm
Retention time:	between 15 and 22 minutes
Loop:	20 µl
Column heater:	28°C

2.5 Statistical analysis

The data sets were subjected to analysis of variance using the General Linear Model (GLM) procedure of the SPSS package program version 10 (SPSS, 1999). The differences between the means were tested using Tukey's multiple test. The correlation coefficients and correlation matrix were also calculated by SPSS program version 10.

3 RESULTS

3.1 Genotypical differences in the composition of asparagus spears and fern

Different factors such as cultivar, fertilization and environmental factors have an influence on the quality of white asparagus, which need to be taken into account when discussing its quality (Zurera et al., 2000). In previous studies, it was shown that there are genotypical differences in spear quality, such as spear diameter, head tightness and fibrousness (Poll, 1995; Paschold et al., 1996 and Mullen et al., 1999). But information about genotypical differences in the content of inorganic and organic compounds in asparagus spears are limited. It was therefore the aim of this study to determine quality parameters such as the mineral composition and the content of organic compounds in spears of different asparagus cultivars and genotypes. Therefore, spear and fern samples of different asparagus cultivars were taken in 2001 from crop performance trials with new cultivars and genotypes in Schleswig-Holstein and Lower Saxony. In these experiments the traditional cultivar *Huchels Alpha* and the new cultivars and genotypes *Ariane, Boonlim, Eposs, Gijnlim, Hannibal, Ramada, Ramos, Ramses, Ranger, Rapid, Ravel, Stamm 12, Stamm 14, Thielim, 17/24, 17/30* and *96012* were tested. The horticultural characteristics of asparagus cultivars and new genotypes are listed in table 2-2.

3.1.1 Mineral nutrient content

Data presented in table 3-1 show that the mineral composition of the spears was similar in all cultivars and differences proved to be only significant for the variables NO_3-N and SO_4-S at the Wiemersdorf test site in Schleswig-Holstein (Table 3-1). The cultivars *Huchels Alpha* and *Gijnlim* showed the highest NO_3-N content with 492 µg g^{-1} and the cultivar *Boonlim* the lowest with 279 µg g^{-1}. The cultivar *Eposs* showed SO_4-S contents that were about six times higher than that of the cultivar *Huchels Alpha* and *Thielim* (Table 3-1). For the other nutrients, N, P, K, Ca, Mg, Fe, Mn, Zn and Cu there were no significant differences among asparagus cultivars grown at the experimental site in Wiemersdorf (Table 3-1).

Table 3-1: Genotypical differences of mineral elemental concentrations in asparagus spears grown in Wiemersdorf, Schleswig-Holstein in 2001.

Cultivar	N	P	K	S	Ca	Mg
	mg g^{-1}					
Boonlim	49.2 a	6.80 a	43.5 a	4.53 a	3.90 a	1.43 a
Eposs	49.9 a	7.47 a	39.9 a	4.93 a	3.47 a	1.49 a
Gijnlim	47.0 a	7.50 a	44.0 a	4.23 a	3.53 a	1.58 a
H. Alpha	47.2 a	7.36 a	39.3 a	4.73 a	3.37 a	1.45 a
Thielim	46.3 a	6.43 a	44.3 a	4.33 a	3.87 a	1.72 a
	NO_3-N	SO_4-S	Fe	Mn	Zn	Cu
	µg g^{-1}					
Boonlim	279 a	50.3 b	60.1 a	8.21 a	56.3 a	19.4 a
Eposs	421 b	145 d	54.0 a	9.17 a	59.6 a	18.2 a
Gijnlim	492 c	107 c	54.1 a	7.34 a	56.9 a	17.8 a
H. Alpha	492 c	23.3 a	46.3 a	8.51 a	60.4 a	17.4 a
Thielim	354 b	22.7 a	47.8 a	7.32 a	52.5 a	20.7 a

Numbers with different characters in the same column indicate statistically different means at the 5% levels (Tukey's test)

At the experimental site in Burgwedel, Lower Saxony statistically significant genotypical differences were found for S, Ca, NO_3-N, SO_4-S, Fe, Mn and Cu (Table 3-2), but none for N, P, K and Mg. The data show that the cultivar *Ramos* and the genotype *96012* had the lowest NO_3-N content with 252 µg g^{-1} and 295 µg g^{-1}, respectively and the cultivar *Ravel* had the highest SO_4-S content with 316 µg g^{-1}. In this study, the concentrations of N, K, Mg, Fe and Mn in asparagus spears were in the same range as found by Makus (1994) but NO_3-N, S, Ca and Cu contents were higher, and Zn lower.

The genotype *17/24* had a 1.53 mg g^{-1} higher S content than the cultivar *Rapid* (Table 3-2). On an average the S concentration of all cultivars was 4.5 mg g^{-1} S in Schleswig-Holstein and 5.9 mg g^{-1} in Lower Saxony. This could be related to a generally lower S supply and atmospheric S deposition in Schleswig-Holstein (Schnug and Haneklaus, 1998).

The mean Mn and SO_4-S of all genotypes grown in Burgwedel was 2.5 and 3.5 times higher and the Ca and Fe content was 61 % and 73.5 % higher than the corresponding value for cultivars grown in Wiemersdorf. Only Cu and K content was 87 % and 13 % lower in the cultivars grown in Burgwedel (Table 3-2).

The results of these investigations indicate that the capability of different asparagus cultivars and new genotypes to use the plant available soil elements is genetically controlled because the mineral nutrient concentrations of 15 asparagus cultivars and genotypes grown under the same conditions were different (Table 3-2).

Table 3-2: Genotypical differences of mineral elemental concentrations in asparagus spears grown in Burgwedel, Lower Saxony in 2001.

Genotype	N	P	K	S	Ca	Mg
	.... $mg\ g^{-1}$					
Ariane	48.6 a	6.65 a	38.0 a	6.32 ab	6.40 ab	1.64 a
Eposs	52.5 a	7.80 a	40.3 a	6.22 ab	3.20 a	1.65 a
Gijnlim	48.3 a	7.58 a	42.1 a	5.60 ab	3.37 a	1.51 a
Hannibal	44.9 a	5.90 a	27.9 a	5.30 ab	11.0 bc	1.56 a
Ramada	50.8 a	7.57 a	30.3 a	6.42 ab	10.7 bc	1.72 a
Ramos	51.1 a	7.65 a	42.1 a	6.20 ab	3.27 a	1.64 a
Ramses	44.7 a	6.30 a	38.1 a	5.82 ab	5.92 a	1.63 a
Ranger	51.1 a	7.62 a	37.5 a	5.60 ab	3.22 a	1.79 a
Rapid	45.4 a	6.30 a	42.2 a	5.07 a	3.22 a	1.45 a
Ravel	48.4 a	6.80 a	41.4 a	6.15 ab	2.83 a	1.66 a
Stamm 12	49.3 a	7.47 a	27.6 a	5.92 ab	15.3 c	1.71 a
Stamm 14	48.0 a	6.47 a	30.3 a	6.02 ab	12.6 c	1.64 a
17/24	49.4 a	7.92 a	44.4 a	6.60 b	3.60 a	1.62 a
17/30	49.9 a	7.50 a	35.1 a	5.85 ab	2.95 a	1.56 a
96012	48.6 a	6.75 a	42.8 a	5.93 ab	3.67 a	1.39 a
	NO_3-N	SO_4-S	Fe	Mn	Zn	Cu
	.... $\mu g\ g^{-1}$					
Ariane	467 ad	277 cd	92.3 c	21.7 c	59.7 abc	7.43 ab
Eposs	589 d	167 ab	85.5 bc	23.4 c	60.8 abc	14.3 bd
Gijnlim	457 ad	238 bcd	93.4 c	17.2 ab	71.8 c	8.30 abc
Hannibal	559 cd	172 ab	92.5 c	20.1 bc	47.6 a	7.02 ab
Ramada	430 ad	231 bcd	103 c	22.4 c	62.5 abc	9.48 abc
Ramos	252 a	215 bc	108 c	24.4 c	67.5 bc	9.09 abc
Ramses	381 ad	189 abc	94.4 c	21.0 bc	55.9 ab	5.24 a
Ranger	367 abc	237 bcd	103 c	22.4 c	63.5 bc	7.10 ab
Rapid	361 abc	117 a	102 c	22.2 c	54.7 ab	11.0 abc
Ravel	394 ad	316 d	104 c	22.9 c	53.7 ab	5.64 a
Stamm 12	523 bcd	235 bcd	97.3 c	20.7 bc	59.0 abc	5.35 a
Stamm 14	325 ab	184 abc	103 c	21.1 bc	56.0 ab	4.13 a
17/24	341 abc	278 cd	64.2 ab	15.8 a	69.2 bc	21.1 d
17/30	308 ab	229 bcd	59.5 a	13.5 a	55.9 ab	20.3 d
96012	295 a	219 bc	64.1ab	15.2 a	56.8 abc	15.1 cd

Numbers with different characters in the same column indicate statistically different means at the 5% levels (Tukey's test)

The cultivars *Eposs* and *Gijnlim* were cultivated at both experimental sites, in Wiemersdorf and Burgwedel. The analysis of variance for these cultivars, site and interaction between cultivar and site (Table 3-3 and 3-4) showed that the difference between both cultivars was significant ($p < 0.05$) for Mn and Cu. The difference between both sites were found to be highly significant ($p < 0.01$) for SO_4-S and Mn and significant ($p < 0.05$) for S and Cu (Table 3-4).

Not only SO_4-S, but also the total S contents of the cultivars *Eposs* and *Gijnlim* were significantly lower on the experimental site in Schleswig-Holstein than in Lower Saxony and this indicates, as mentioned before, a lower S supply of the crop (Schnug and Haneklaus, 1998). The SO_4-S content of the cultivar *Gijnlim* grown in Schleswig-Holstein was more than 130 µg g^{-1} lower than that in Lower Saxony (Table 3-4). Data presented in table 3-3 and 3-4 show that the mineral content in spears of both cultivars was higher in Burgwedel than in Wiemersdorf with the exception of Cu.

Table 3-3: Mean values and results of the F-test for the macro-nutrient concentrations in spears of two asparagus cultivars grown in Wiemersdorf (WD) and Burgwedel (BW) in 2001.

Cultivar	Site	**N**	**P**	**K**	**S**	**Ca**	**Mg**
		.... mg g^{-1}........					
Eposs	WD	49.9	7.47	39.9	4.93	3.47	1.49
	BW	52.5	7.80	40.3	6.22	3.20	1.65
Gijnlim	WD	47.0	7.50	44.0	4.23	3.53	1.58
	BW	48.3	7.58	42.1	5.60	3.37	1.51
Cultivar (V)		ns	ns	ns	ns	ns	ns
Site (S)		ns	ns	ns	**	ns	ns
V × S		ns	ns	ns	ns	ns	ns

*, **, *** and ns significant at 0.05, 0.01, 0.001 and non significant, respectively

Table 3-4: Mean values and results of the F-test for nitrate, sulfate and micro-nutrient concentrations in spears of two asparagus cultivars grown in Wiemersdorf (WD) and Burgwedel (BW) in 2001.

Cultivar	Site	**NO_3-N**	**SO_4-S**	**Fe**	**Mn**	**Zn**	**Cu**
		.... $\mu g\ g^{-1}$					
Eposs	WD	421	147	45.0	9.2	59.6	18.2
	BW	589	167	85.5	23.4	60.8	14.3
Gijnlim	WD	492	107	54.1	7.3	56.9	17.8
	BW	457	238	93.4	17.2	71.8	8.3
Cultivar (V)		ns	ns	ns	**	ns	*
Site (S)		ns	***	ns	***	ns	**
V × S		ns	ns	ns	ns	ns	ns

*, **, *** and ns significant at 0.05, 0.01, 0.001 and non significant, respectively

The results presented in table 3-5 and 3-6 show the effect of genotype on the mineral element contents of asparagus fern. At the experimental site in Wiemersdorf, Schleswig Holstein, statistically significant genotypical differences were found for K, Mg, NO_3-N, Fe, Mn, Zn and Cu, but none for N, P, S, Ca and SO_4-S (Table 3-5).

Data presented in table 3-6 show that the effect of genotype was not significant for the total of N, P and K content at the experimental site in Burgwedel, Lower Saxony, but differences proved to be significant for S, Ca, Mg, NO_3-N, SO_4-S, Fe, Mn, Zn and Cu. Data presented in table 3-5 and 3-6, it reveal that the average absolute concentrations of the K, S, Ca, NO_3-N, SO_4-S, Fe and Mn content in fern of asparagus cultivars grown in Burgwedel, Lower Saxony, were higher by 3.20 mg g^{-1}, 1.8 mg g^{-1}, 3.8 mg g^{-1}, 39.8 µg g^{-1}, 416 µg g^{-1}, 271 µg g^{-1} and 68.7 µg g^{-1} than the average of the cultivars grown in Wiemersdorf, Schleswig-Holstein and the total N, Zn and Cu lower by 4.0 mg g^{-1} 5.7 µg $g^{-1}$and 2.9 µg g^{-1}, respectively. The concentration of all elements was in the same sufficiency range as reported by Mills and Benton Jones (1996) for asparagus fern.

Table 3-5: Genotypical differences of mineral elemental concentrations in asparagus fern grown in Wiemersdorf, Schleswig-Holstein in 2001.

cultivar	**N**	**P**	**K**	**S**	**Ca**	**Mg**
	.... mg g^{-1}..............					
Boonlim	39.9 a	2.37 a	21.5 c	5.27 a	13.4 a	3.10 b
Eposs	39.4 a	2.47 a	17.3 a	5.05 a	14.3 a	3.13 b
Gijnlim	43.0 a	2.63 a	19.4 b	5.42 a	12.0 a	2.29 b
Thielim	40.4 a	2.53 a	21.3 c	5.07 a	13.7 a	2.65 a
	NO_3-N	**SO_4-S**	**Fe**	**Mn**	**Zn**	**Cu**
	.... µg g^{-1}..............					
Boonlim	180 a	338 a	96.7 a	38.8 a	19.7 a	9.37 a
Eposs	290 b	347 a	94.7 a	52.8 b	18.3 a	8.54 a
Gijnlim	156 a	448 a	135.7 b	38.8 a	19.6 a	11.4 b
Thielim	209 a	326 a	92.9 a	35.7 a	22.5 b	8.30 a

Numbers with different characters in the same column indicate statistically different means at the 5% levels (Tukey's test)

The analysis of variance for the cultivars *Eposs* and *Gijnlim* showed that the differences between the cultivars *Eposs* and *Gijnlim* were only significant for Mg in the fern but the differences between both site were significant for all mineral contents except NO_3-N (Table 3-7 and 3-8). The Mineral concentration in the fern of the cultivars *Eposs* and *Gijnlim* grown at two locations is presented in table 3-7 and 3-8. The concentration of the K, S, Ca, SO_4-S Fe and Mn in the fern of both cultivars was higher in Burgwedel than in Wiemersdorf while the N, P, Mg and Zn concentrations were lower. The interaction between cultivar and site was significant for P, S, Mg, Mn, and Cu content.

Table 3-6: Genotypical differences of mineral elemental concentrations in asparagus fern grown in Burgwedel, Lower Saxony in 2001.

Genotype	N	P	K	S	Ca	Mg
	...... $mg\ g^{-1}$					
Ariane	35.2 a	2.08 a	23.3 a	7.05 b	16.3 ab	2.75 cd
Eposs	37.3 a	2.40 a	23.4 a	6.32 a	17.1 bcd	1.90 a
Gijnlim	37.3 a	2.30 a	22.3 a	7.13 b	16.8 ad	1.73 a
Hannibal	39.0 a	2.15 a	23.2 a	6.20 a	16.8 ad	2.78 e
Ramada	37.5 a	2.28 a	23.8 a	7.15 b	16.9 ad	1.82 a
Ramos	38.2 a	2.20 a	21.0 a	7.65 c	17.7 bcd	2.39 bcd
Ramses	37.3 a	2.18 a	25.6 a	7.05 b	17.3 bcd	2.50 cd
Ranger	36.1 a	2.13 a	24.2 a	8.28 d	18.0 d	2.80 de
Rapid	37.6 a	2.37 a	23.5 a	7.80 c	17.5 bcd	2.06 ab
Ravel	37.6 a	2.70 a	23.2 a	8.30 d	17.2 bcd	1.72 a
Stamm 12	38.4 a	2.00 a	23.0 a	5.57 a	15.6 a	2.60 cd
Stamm 14	37.3 a	2.08 a	23.7 a	5.70 a	16.4 abc	2.71 cd
17/24	35.3 a	2.50 a	22.1 a	7.72 c	17.8 cd	2.37 bcd
17/30	37.1 a	2.52 a	21.5 a	5.77 a	16.6 ad	2.07 ab
96012	36.3 a	2.35 a	22.2 a	8.40 d	18.0 d	2.06 ab
	NO_3-N	SO_4-S	Fe	Mn	Zn	Cu
	...... $\mu g\ g^{-1}$					
Ariane	136 ab	702 cd	322 a	94.7 ab	11.4 a	5.51 a
Eposs	232 bcd	671 cd	396 ab	104 ab	14.4 bcd	8.83 c
Gijnlim	288 cde	656 c	387 ab	127 bc	16.7 d	6.20 a
Hannibal	407 e	507 b	332 a	112 ab	11.8 ab	5.73 a
Ramada	103 ab	819 ef	408 abc	146 c	14.5 bcd	5.51 a
Ramos	86.2 a	988 gh	397 ab	119 abc	12.8 abc	5.73 a
Ramses	301 de	765 de	361 ab	94.4 ab	14.3 abc	4.61 a
Ranger	116 ab	1013 h	404 abc	98.3 ab	15.9 d	5.07 a
Rapid	361 de	897 fg	433 bc	118 abc	14.4 bcd	5.89 a
Ravel	162 abc	1056 hi	382 ab	123 abc	15.6 d	6.98 b
Stamm 12	348 de	396 a	311 a	90.3 a	12.7 abc	5.36 a
Stamm 14	235 bcd	494 b	359 ab	104 ab	11.9 ab	5.67 a
17/24	318 de	107 hi	383 ab	96.7 ab	17.1 d	7.29 b
17/30	291cde	519 b	374 ab	104 ab	16.0 d	9.88 c
96012	344 de	1151 i	395 c	122 abc	14.8 cd	7.27 b

Numbers with different characters in the same column indicate statistically different means at the 5% levels (Tukey's test)

Table 3-7: Mean values and results of the F-test for macro-nutrients concentration in fern of two asparagus cultivars grown in Burgwedel (BW) and Wiemersdorf (WD) in 2001.

Culivar	**Site**	**N**	**P**	**K**	**S**	**Ca**	**Mg**
		.... **mg g^{-1}**					
Eposs	WD	39.4	2.47	17.3	5.05	14.3	3.13
	BW	37.3	2.40	23.4	6.32	17.1	1.90
Gijnlim	WD	43.0	2.63	19.4	5.42	12.0	2.29
	BW	37.3	2.30	22.3	7.13	16.8	1.73
Cultivar (V)		ns	ns	ns	ns	ns	**
Site (S)		**	**	**	**	**	**
V × S		ns	**	ns	*	ns	*

*, **, *** and ns significant at 0.05, 0.01, 0.001 and non significant, respectively

Table 3-8: Mean values and results of the F-test for nitrate, sulfate and micro-nutrients concentration in fern of two asparagus cultivars grown in Burgwedel (BW) and Wiemersdorf (WD) in 2001.

Cultivar	**Site**	**NO_3-N**	**SO_4-S**	**Fe**	**Mn**	**Zn**	**Cu**
		.... **µg g^{-1}**					
Eposs	WD	290	347	94.7	52.8	18.3	8.54
	BW	232	671	396	104	14.4	8.83
Gijnlim	WD	156	448	136	38.8	19.6	11.4
	BW	287	656	387	127	16.7	6.2
Cultivar (V)		ns	ns	ns	ns	ns	ns
Site (S)		ns	**	**	**	**	**
V × S		ns	ns	ns	**	ns	**

*, **, *** and ns significant at 0.05, 0.01, 0.001 and non significant, respectively

Relationship between the mineral nutrient content in asparagus spears and fern was examined. There was a significant relationship between the S, SO_4-S, Mn, Fe and Cu content in asparagus spears and the corresponding nutrient concentrations in the fern (Fig 3-1 – 3-5). For all other nutrients no significant relationship was found (see appendix fig. 7-1) .

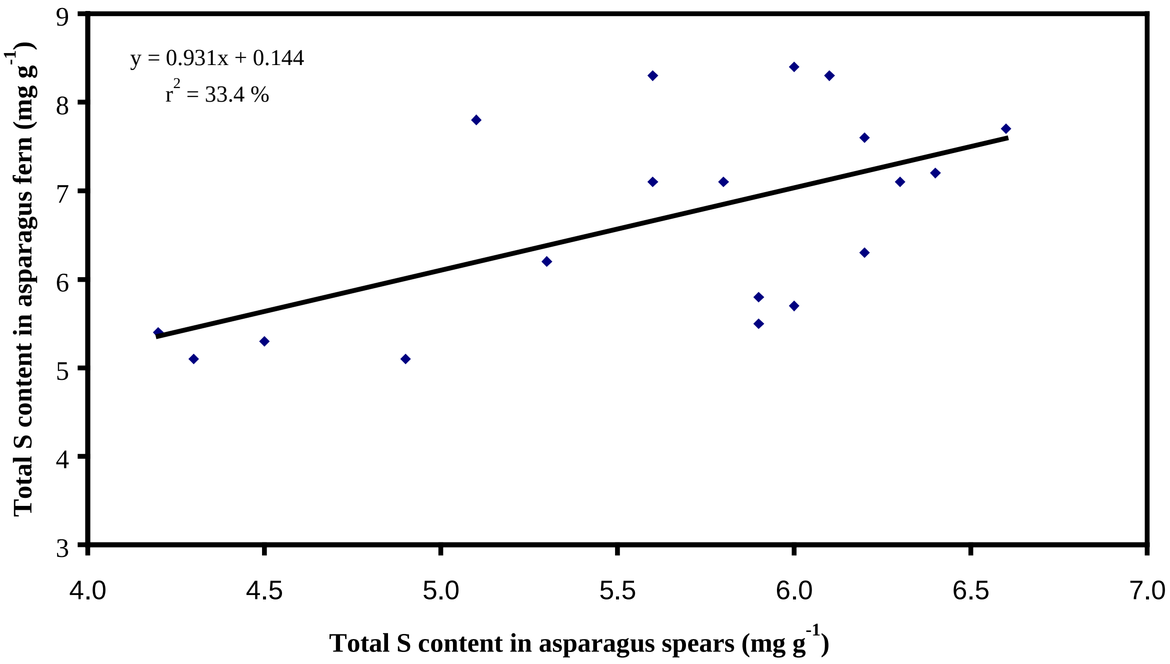

Fig 3-1: Relationship between total S content in asparagus spears and fern.

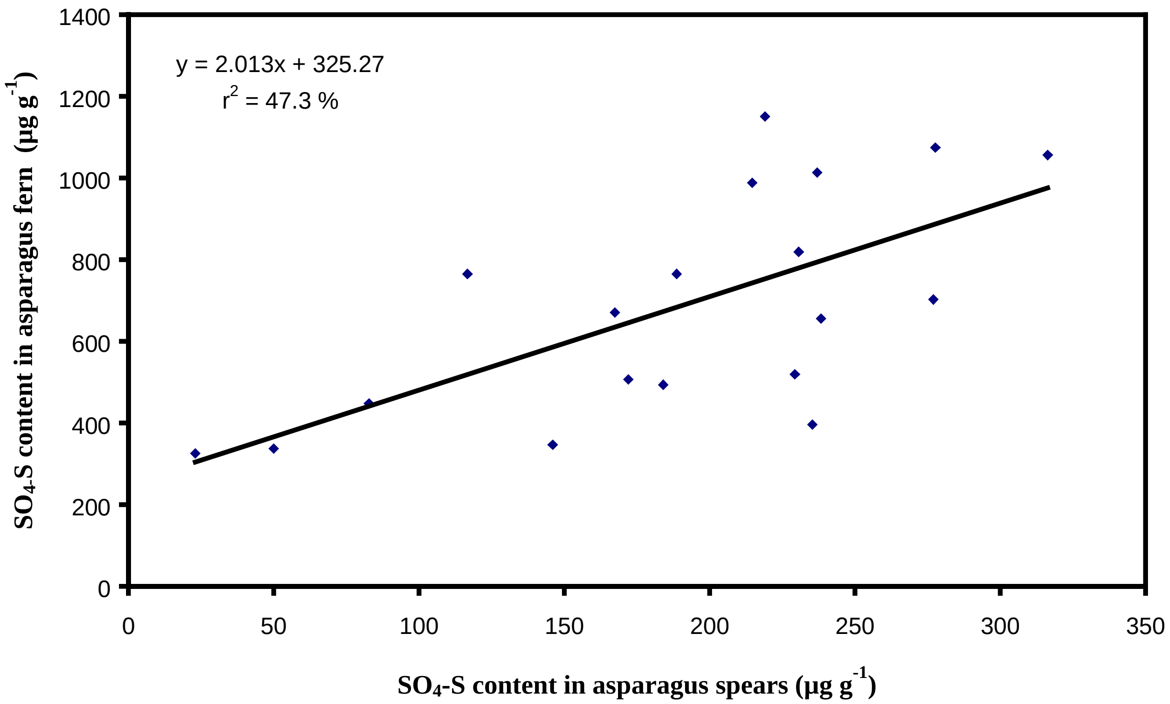

Fig 3-2: Relationship between SO_4-S content in asparagus spears and fern.

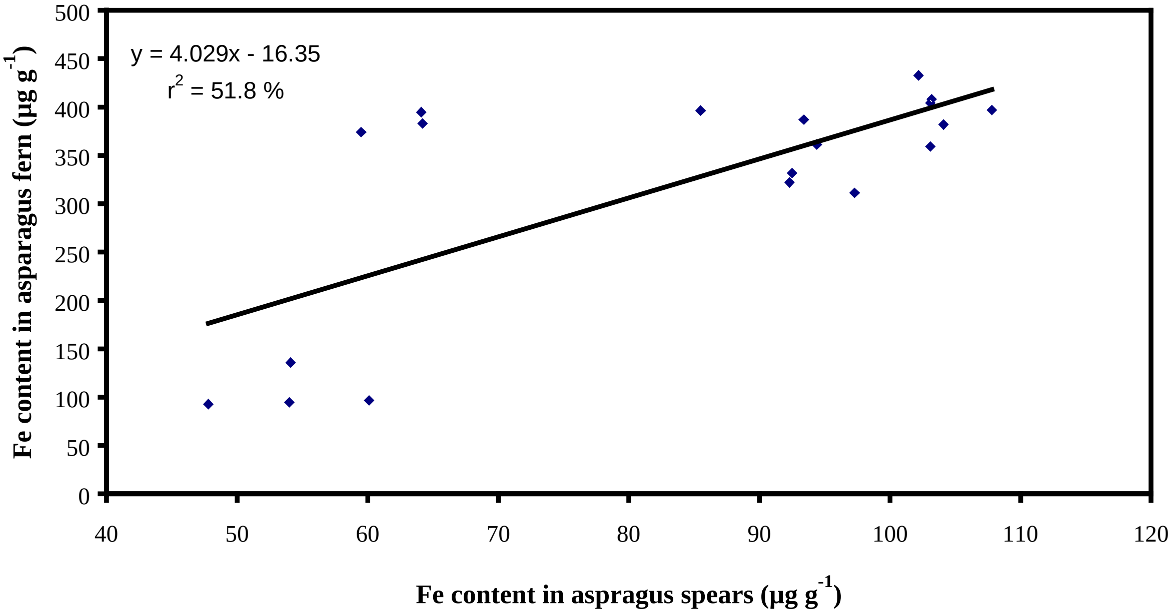

Fig 3-3: Relationship between Fe content in asparagus spears and fern.

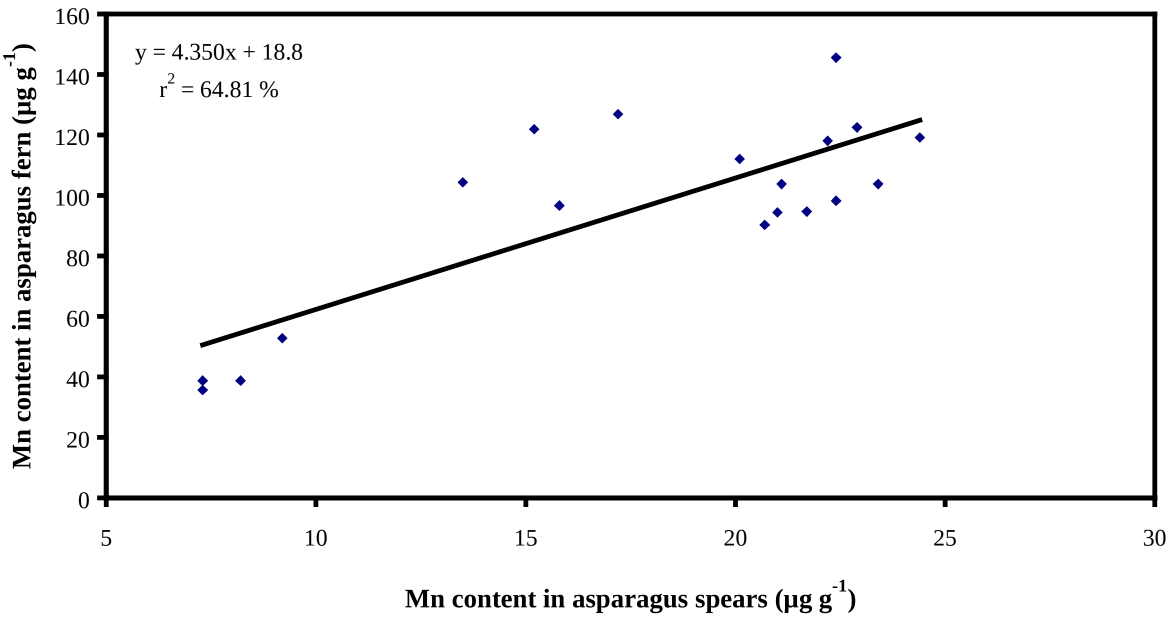

Fig 3-4: Relationship between Mn content in asparagus spears and fern.

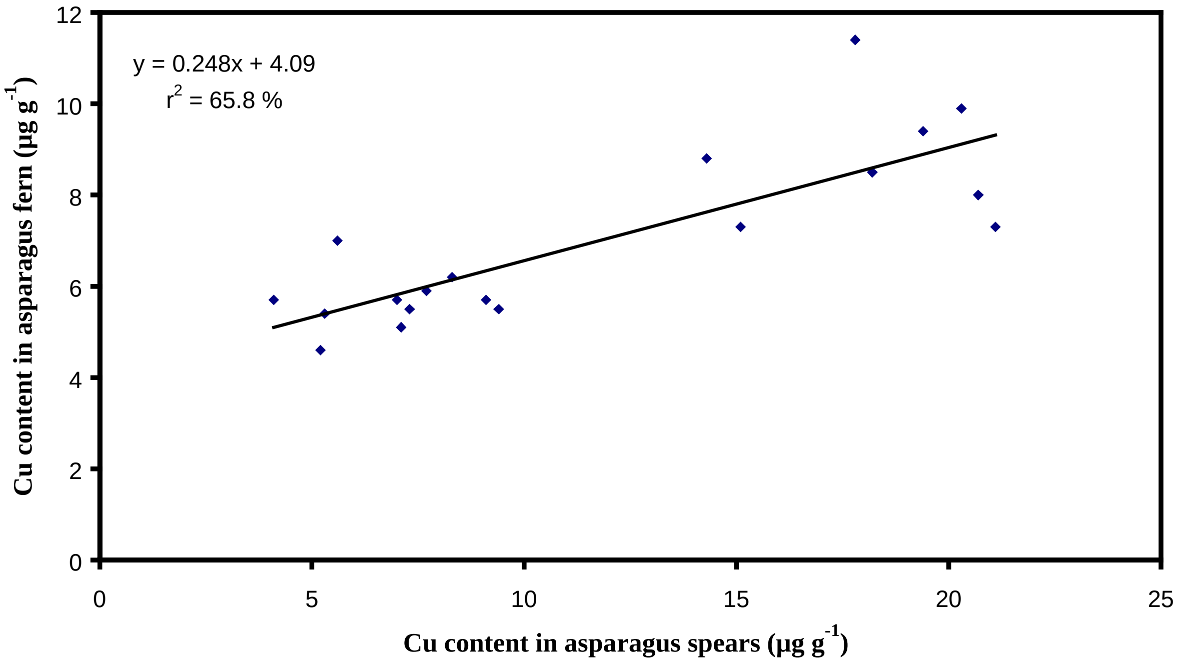

Fig 3-5: Relationship between Cu content in asparagus spears and fern.

3.1.2 Organic compounds

Usually, reduced S is rapidly incorporated into organic molecules. Cysteine is the first stable organic S-form and precursor of other amino acids such as cystine and methionine and several S-containing biochemical compounds (Amberger, 1979).

The effect of genotype on the protein content of asparagus spears and fern, cysteine and glutathione of asparagus spears grown at the experimental site in Wiemersdorf is presented in table 3-9. Differences among cultivars proved to be not significant for the protein content in spears and fern. Glutathione and cysteine were determined in this study only in spear samples. The data show that differences in the glutathione and cysteine content of spears were significant. The cultivars *Huchels Alpha* and *Boonlim* had the highest glutathione content with 25.3 µmol g^{-1} and 25.2 µmol g^{-1} and the cultivar *Thielim* had the lowest content with 17.6 µmol g^{-1}.

At the experimental site in Burgwedel the protein content of asparagus spears and fern ranged from 27.9 to 32.8 % and from 21.1 to 24.4 %, respectively (Fig. 3-6). Differences between genotypes proved to be not significant for the protein content in asparagus spears and fern. Asparagus was found to be a good source of protein (Lopez et al., 1996). Figure 3-7 shows that differences in the cysteine content among asparagus genotypes grown in Burgwedel were not significant.

Glutathione acts as antioxidant, it considerably involved in the immune system (Galen, 2000). Differences in the glutathione content between asparagus genotypes grown at the experimental site in Burgwedel were significant. Tendentiously, the cultivar *Eposs* had the highest glutathione content with 20.5 µmol g^{-1} and the cultivar *Hannibal* had the lowest content with 13.2 µmol g^{-1} (Fig. 3-7). Pressman (1997) reported that the mean content of glutathione in asparagus spears was 26 mg 100 g^{-1} fresh spears but Saito et al (2000) found that glutathione content in asparagus spears was 40 – 45 mg 100 g^{-1}. In this study, glutathione content in fresh white asparagus spears ranged from 24.5 to 35.7 mg 100 g^{-1}.

Table 3-9: Genotypical differences in the protein, cysteine and glutathione content of asparagus grown in Wiemersdorf in 2001.

Cultivar	**Protein (%)**		**Cysteine (µmol g^{-1})**	**Glutathione (µmol g^{-1})**
	Spear	Fern	Spear	
Boonlim	30.7 a	24.9 a	3.10 b	25.2 b
Eposs	31.2 a	24.6 a	2.48 ab	18.7 ab
Gijnlim	29.4 a	26.9 a	2.37 a	23.9 ab
H. Alpha	29.5 a	--	2.39 a	25.3 b
Thielim	28.9 a	25.3 a	2.34 a	17.6 a

-- not determined
Numbers with different characters in the same column indicate statistically different means at the 5% levels (Tukey's test)

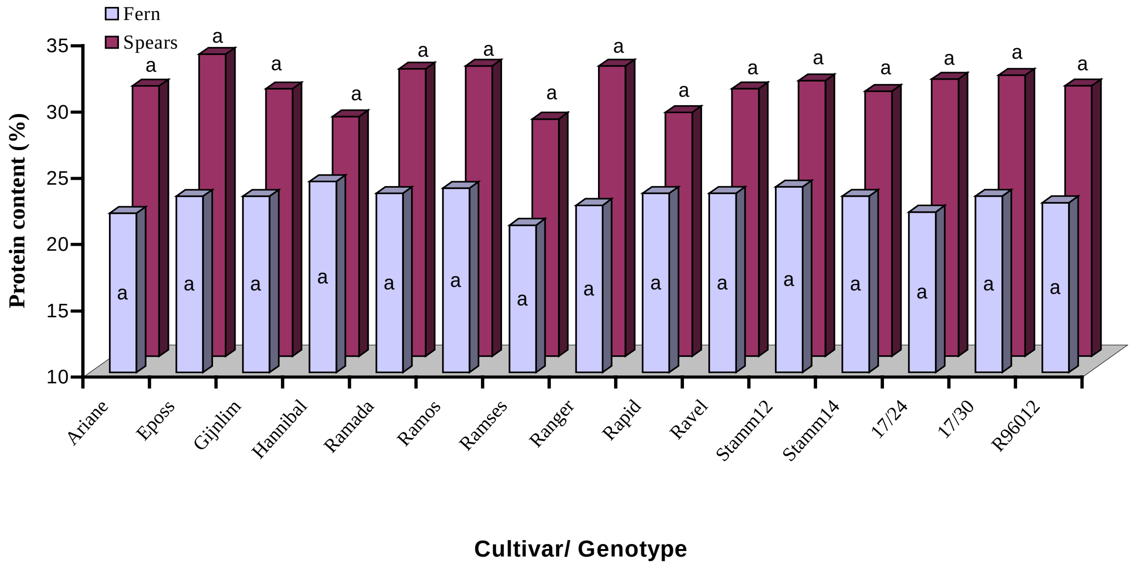

Fig. 3-6: Protein content of asparagus spears and fern of different cultivars and genotypes grown in Burgwedel in 2001; differences between spears and fern statistically significant and differences between cultivars not significant (means compared by the Tukey´s test P< 0.05)

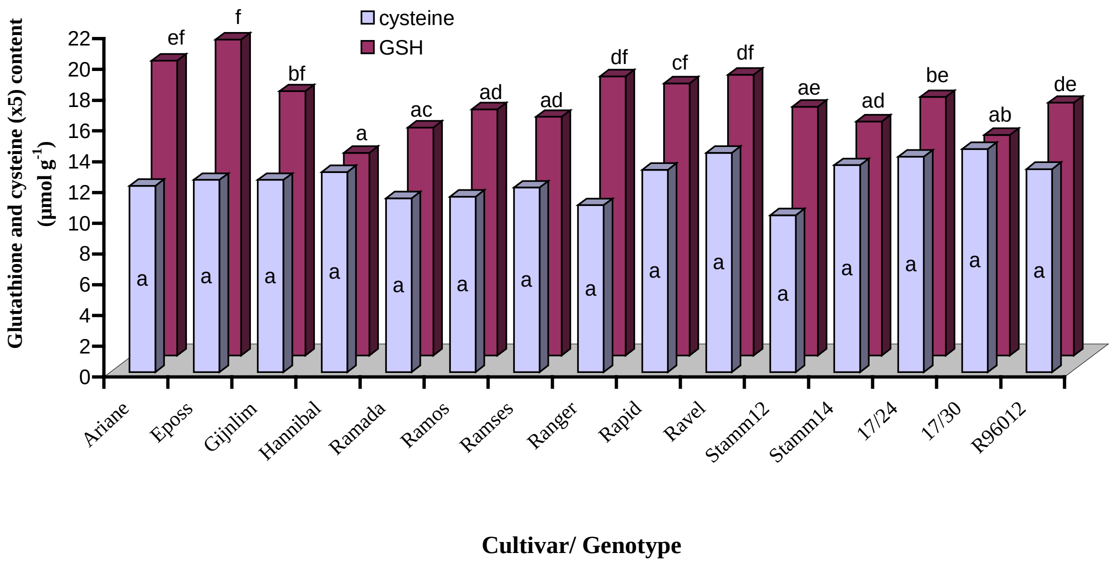

Fig. 3-7: Glutathione (GSH) and Cysteine (×5) content in spears of different asparagus cultivars and genotypes grown in Burgwedel in 2001 (means compared by the Tukey´s test)

There were no significant differences between the cultivar *Eposs* and *Gijnlim* grown on both experimental sites in Wiemersdorf and Burgwedel for the protein, cysteine and glutathione content. Differences between sites were also not significant for the organic compounds (Table 3-10).

Table 3-10: Mean values and results of F-test for the organic compounds of two asparagus cultivars grown in Burgwedel (BW) and Wiemersdorf (WD) in 2001.

Cultivar	Site	Protein (%)	Cysteine (µmol g^{-1})	Glutathione (µmol g^{-1})
Eposs	WD	31.2	2.48	25.2
	BW	32.8	2.50	20.6
Gijnlim	WD	29.4	2.37	18.7
	BW	30.2	2.50	17.2
Cultivar (V)		ns	ns	ns
Site (S)		ns	ns	ns
V x S		ns	ns	ns

*, **, *** and ns significant at 0.05, 0.01, 0.001 and non significant, respectively

3.2 Influence of the cultivation region on the composition of asparagus spears

Information on regional differences in the content of mineral and organic compounds in asparagus spear is scarce. The results from crop performance trials already indicated the significance of different cultivation regions on the nutrient concentration of asparagus (chapter 3.1). In 2000 extended field surveys were conducted in the areas of Braunschweig and Erfurt in order to study the impact of different growth conditions on the mineral composition and organic compounds content of asparagus spears.

3.2.1 Mineral nutrient content

Spear samples were collected from different asparagus cultivars (*Bonlim, Eposs, Gijnlim, Huchels Alpha, Huchels Leistungsauslese, Mars, Rekord, Vulkan and Schwetzinger Meisterschuss*) in Braunschweig and from *Bonlim, Eposs, Dimlin, Helio* and *Gijnlim* in Erfurt. In table 3-11 and 3-13 mean values for all cultivars are presented. Regional differences in the composition of asparagus spears were significant for Ca, Mg and SO_4-S. Individual data of spears for the cultivars are given in the appendix (Table 7-2 to 7-5).

In case of Ca and Mg the mean elemental concentration was 380 µg g^{-1} and 80 µg g^{-1} higher in the area of Braunschweig than in Erfurt. But the SO_4-S concentration was 23.3 µg g^{-1} higher in the area of Erfurt than Braunschweig (Table 3-11 and 3-13). Difference in the mineral composition between the two areas was not significant for P, S, K, Fe, Mn, Zn and Cu (Table 3-11). The results reveal that the concentration of the P, Ca, Fe, Zn and Cu content was distinctly lower in both region than the corresponding values given as average content in literature (Souci et al., 2000). The reason is possibly that the nutritional value refer to the edible parts while in this study the mineral concentration was determined in unpeeled spears. The investigation of Amaro et al. (1997) confirm that the mineral concentration of peeled spears was higher than mineral concentration in washed spears.

Nitrate is one of the most important non-protein N-compounds, which particularly enriches in plant tissue (Mills and Benton Jones, 1996). It is clear from the data presented in table 3-11 that the NO_3-N concentrations were with about 519 µg g^{-1} distinctly above the mean nutritional value of 229 µg g^{-1} NO_3-N given by Souci et al. (2000) but still below the maximum value 677 µg g^{-1} NO_3-N in other vegetables given by the same author. The coefficient of variation was high for SO_4-S and NO_3-N in both sites and Mn in Braunschweig. For Ca and Mg it was found that the coefficient of variation was higher in the area of Erfurt than Braunschweig (Table 3-13).

3.2.2 Organic compounds

The cultivation region had no significant effect on the total content of protein, cysteine and glutathione in asparagus spears (Table 3-12). Similar results were found in the previous chapter (Table 3-10). The glutathione content varied only a little from 38.3 and 41 mg 100 g^{-1} in fresh spears in Erfurt and Braunschweig and thus was considerably higher than these reported by Pressman (1997) with 26 mg 100 g^{-1} and in the same range as found by Saito et al. (2000). In this study, the cysteine content was on an average 2 µmol g^{-1} higher than in the cultivar field trials (Chapter 3.1.2). Coefficient of variation was high for cysteine and glutathione and low for protein in both regions. But the coefficient of variation of glutathione was higher in Erfurt than in Braunschweig area (Table 3-12).

Table 3-11: Influence of the cultivation region on the mineral elemental concentrations of asparagus spears (mean values for all cultivars) in 2000.

Site	**Macro-nutrients**					
	N	**P**	**S**	**K**	**Ca**	**Mg**
	.... mg g^{-1}					
Braunschweig	42.5 a	3.78 a	5.23 a	29.0 a	2.39 b	0.92 b
Erfurt	44.1 a	3.81 a	5.24 a	28.2 a	2.01 a	0.84 a
	NO_3-N	**SO_4-S**	**Micro-nutrients**			
			Fe	**Mn**	**Zn**	**Cu**
	.... µg g^{-1}					
Braunschweig	538 a	88.7 a	66.7 a	14.2 a	51.1 a	12.3 a
Erfurt	514 a	112.3 b	59.9 a	13.5 a	52.5 a	16.6 a

Numbers with different characters in the same column indicate statistically different means at the 5% levels (Tukey's test)

Table 3-12: Influence of the cultivation region on the protein, cysteine and glutathione content of asparagus spear (dry weight basis) (Mean values for all cultivars) in 2000.

Site	**Protein** (%)				**Cysteine** (µmol g^{-1})				**Glutathione** (µmol g^{-1})			
	min	max	mean	cv. (%)	min	max	mean	cv. (%)	min	max	mean	cv. (%)
Braunsch.	22.4	29.6	26.6 a	7.0	2.5	9.4	4.8 a	40.2	8.4	31.9	20.5 a	43.4
Erfurt	23.3	30.3	27.6 a	6.1	2.0	7.4	4.7 a	35.4	7.2	32.4	19.5 a	51.5

Numbers with different characters in the same column indicate statistically different means at the 5% levels (Tukey's test); cv: Coefficient of variation.

Table 3-13: Descriptive statistics for the chemical composition of asparagus spears grown in two cultivation regions in 2000.

Site	**Min.**	**Max.**	**mean**	**Median**	**cv %**	**Min.**	**Max.**	**mean**	**Median**	**cv %**
	N (mg g^{-1})					**P (mg g^{-1})**				
Braunsch	35.8	47.4	42.5	42.6	7.0	3.4	4.2	3.8	3.8	5.5
Erfurt	37.2	48.4	44.1	44.5	6.1	3.4	5.3	3.9	3.8	12.3
	K (mg g^{-1})					**S (mg g^{-1})**				
Braunsch.	23.9	34.7	29.0	28.9	9.5	3.8	6.7	5.23	5.1	15.4
Erfurt	22.1	32.6	28.2	26.2	15.9	4.2	6.3	5.24	4.9	16.9
	Ca (mg g^{-1})					**Mg (mg g^{-1})**				
Braunsch.	1.1	3.1	2.39	1.9	21.9	0.7	1.2	0.92	0.9	14.3
Erfurt	1.4	2.4	2.01	2.1	24.5	0.4	1.3	0.84	0.8	22.1
	Fe (µg g^{-1})					**Zn (µg g^{-1})**				
Braunsch.	53.3	81.6	66.7	65.5	11.1	44.6	59.4	51.1	49.6	9.6
Erfurt	48.5	104	59.9	57.8	16.7	46.1	60.8	52.5	51.6	7.0
	Mn (µg g^{-1})					**Cu (µg g^{-1})**				
Braunsch.	9.8	20.4	14.2	13.2	22.9	7.7	16.3	12.3	12.5	16.1
Erfurt	10.8	21.2	13.5	13.2	18.1	10.2	21.5	16.6	17.1	16.9
	SO_4-S (µg g^{-1})					**NO_3-N (µg g^{-1})**				
Braunsch.	39.7	181	88.7	86.6	46.7	197	901	538	525	29.3
Erfurt	67.6	182	112	107	24.5	239	747	514	494	26.1

cv. Coefficient of variation

The results presented in chapter 3.1 and 3.2 can be summarized as follows:

1. Significant differences were found in the SO_4-S, NO_3-N and glutathione content for different asparagus cultivars grown in Wiemersdorf.
2. Asparagus cultivars and genotypes grown in Burgwedel showed significant differences in glutathione, S, Ca, NO_3-N, SO_4-S, Mn, Fe and Cu content.
3. The cultivar *Ramos* and the genotype *96012* had the lowest NO_3-N content with 252 and 295 µg g^{-1} (dw), respectively.
4. Asparagus cultivars and genotypes showed no significant site specific differences in the protein content.
5. Asparagus cultivars grown in Lower Saxony had a higher S and SO_4-S content than those grown in Schleswig-Holstein.
6. Regional differences in the composition of asparagus spears were significant for Ca, Mg and SO_4-S between Braunschweig and Erfurt.
7. There were significant relationships between the content of S, SO_4-S, Mn, Fe and Cu in asparagus spears and fern.

3.3 Influence of sulfur fertilization on the chemical composition of asparagus spears

Sulfur deficiency is the most wide spread nutrient disorder in northern Europe and has a strong impact on crop productivity and quality (Schnug, 1990; Khalaf and Taha, 1988; Haneklaus et al., 1999; Lancaster et al., 2001). S is a major plant nutrient and particularly in high productive agricultural system the S demand is only warranted by fertilization (Schnug, 1988; Kleinhenz, 1999). Schnug (1990) recommended S fertilization for the enhancement of the quality of vegetable and emphasized the requirement of sulfur compounds for resistance against pests and diseases. In this chapter the results of field experiments to investigate the influence of S fertilization on the mineral composition and protein, cysteine and glutathione content in spears of four asparagus cultivars are reported.

3.3.1 Mineral nutrient content

A field trial was carried out at the experimental site in Rietze in 1999 and 2000 with the cultivar *Huchels Alpha*. 100 kg ha^{-1} S as one dose were applied on 3 July 1998 and on 24 June 1999. Spear samples were taken at three sampling dates, two in 1999 and one in 2000. The effect of S fertilization on the mineral content of asparagus spears of the cultivar *Huchels Alpha* at the different sampling dates is shown in table 3-14. S fertilization had a significant influence on the S and SO_4-S content of asparagus spears at all three sampling dates (Table 3-14). At the first sampling date S fertilization increased the S content by calculate 0.82 mg g^{-1} while at the third sampling date these value was significantly higher with 1.09 mg g^{-1}. Simultaneously, the SO_4-S content increased by 28.6 µg g^{-1} in the first sampling and by 35 µg g^{-1} in the third one (Table 3-14).

All other nutrient contents were not affected by the treatment with the exception of Fe at the first sampling date. Where the Fe content was higher in the control plants than in the fertilized plots (Table 3-14).

Table 3-14: Effect of sulfur fertilization on the mineral content of asparagus spears (cultivar *Huchels Alpha* grown at Rietze in 1999 and 2000).

Treatment	N	P	K	S	Ca	Mg
	.... mg g^{-1}					
1999 1st sampling						
Control	40.4 a	4.15 a	29.1 a	4.42 a	2.40 a	1.39 a
100 kg ha^{-1} S	40.4 a	4.95 a	32.1 a	5.24 b	2.60 a	1.38 a
1999 2nd sampling						
Control	39.7 a	4.45 a	32.9 a	4.76 a	2.65 a	1.44 a
100 kg ha^{-1} S	40.1 a	4.85 a	34.8 a	5.48 b	2.50 a	1.41 a
2000 1st sampling						
Control	45.3 a	6.23 a	31.8 a	4.47 a	3.07 a	1.30 a
100 kg ha^{-1} S	42.4 a	6.17 a	32.3 a	5.56 b	4.13 a	1.32 a
	NO_3-N	**SO_4-S**	**Fe**	**Mn**	**Zn**	**Cu**
	.... µg g^{-1}					
1999 1st sampling						
Control	375 a	79.4 a	99.7 b	13.4 a	50.7 a	11.1 a
100 kg ha^{-1} S	332 a	108 b	76.3 a	12.0 a	48.1 a	10.9 a
1999 2nd sampling						
Control	244 a	102 a	69.1 a	13.9 a	48.4 a	10.2 a
100 kg ha^{-1} S	259 a	112 a	73.7 a	11.9 a	50.1 a	11.0 a
2000 1st sampling						
Control	470 a	136 a	71.5 a	9.76 a	50.7 a	11.5 a
100 kg ha^{-1} S	462 a	171 b	94.4 a	9.47 a	53.9 a	12.6 a

Numbers with different characters in the same column indicate statistically different means at the 5% levels (Tukey's test)

The second field trial was carried out at Veltenhof in 1999 with the cultivar *Rekord*. 100 kg ha^{-1} S was applied on 16 June in 1988 and 1999. Spear samples were taken at two sampling dates (17 May and 9 June) in 1999. S fertilization had a significant influence on the S content in asparagus spears of the cultivar *Rekord*, while all other macro-nutrients were not affected by the treatment (Table 3-15). At the first sampling date S fertilization increased the S content by 0.92 mg g^{-1} while at later, second sampling the difference was only 0.72 mg g^{-1}. The NO_3-N content was significantly affected by S fertilization at both sampling dates. The SO_4-S content was significantly higher at the first spear sampling date (Table 3-15). On this site the S fertilization had no influence on the total content of micro-nutrients (Table 3-15).

Table 3-15: Effect of sulfur fertilization on mineral content of asparagus spears (cultivar *Rekord* grown in Veltenhof in 1999).

Treatment	**N**	**P**	**K**	**S**	**Ca**	**Mg**
	.... mg g^{-1}					
1^{st} sampling						
Control	36.6 a	4.60 a	30.1 a	4.28 a	2.85 a	1.23 a
100 kg ha^{-1} S	36.8 a	4.25 a	30.4 a	5.20 b	2.60 a	1.27 a
2^{nd} sampling						
Control	39.3 a	4.95 a	35.4 a	5.02 a	2.85 a	1.46 a
100 kg ha^{-1} S	39.9 a	5.05 a	34.9 a	5.74 b	2.90 a	1.45 a
	NO_3-N	**SO_4-S**	**Fe**	**Mn**	**Zn**	**Cu**
	.... µg g^{-1}					
1^{st} sampling						
Control	130 a	91.0 a	91.5 a	15.3 a	43.1 a	12.0 a
100 kg ha^{-1} S	221 b	124 b	87.2 a	14.9 a	42.5 a	10.8 a
2^{nd} sampling						
Control	146 a	68.8 a	67.7 a	14.9 a	39.9 a	9.22 a
100 kg ha^{-1} S	228 b	73.0 a	60.8 a	14.4 a	39.5 a	9.99 a

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test)

The third field trial was carried out at the experimental site in Gross Schwülper in 1999 and 2000 with the cultivar *Schwetzinger Meisterschuss*. 100 kg ha^{-1} S were applied on 3 July 1988 and 24 June 1999. Spear samples were taken at three sampling dates, two in 1999 and one in 2000. The S fertilization had no significant influence on the total S and SO_4-S content of the cultivar *Schwetzinger Meisterschuss* (Table 3-16). This could be due to the high mineral sulfur in the soil in this site (Table 2-3) and the age of plants, while plants grown in this experiment were twelve years old. But it is remarkably that in the second year of experimentation the control plots showed a significantly higher NO_3-N content than these plots, which received S fertilization (Table 3-16). The concentration of N, P and S in spears of the cultivar *Schwetzinger Meisterschuss* in the first year of experimentation was lower than those found by Makus (1995) in the spears of the white asparagus cultivar *Jersey Giant* grown in silt loam soil but the K content was in the similar range (27.7 mg g^{-1}). The concentration of Fe, Mn, Zn, Cu and NO_3-N in the cultivar *Jersey Giant* was 126 µg g^{-1}, 17 µg g^{-1}, 61 µg g^{-1}, 11 µg g^{-1} and 372.8 µg g^{-1} , respectively.

It was found from the comparison between all trials in different sites for micro-nutrients that crop performance trials had the highest total content of Fe, Mn and Zn with an average 83.3 µg g^{-1}, 17.7 µg g^{-1} and 58.3 µg g^{-1}, respectively. But the cultivars grown in the experimental site of Erfurt had the highest Cu content with an average 16.6 µg g^{-1}.

Table 3-16: Effect of sulfur fertilization on the mineral content of asparagus spears (cultivar *Schwetzinger Meisterschuss* grown at Gross Schwülper in 1999 and 2000).

Treatment	**N**	**P**	**K**	**S**	**Ca**	**Mg**
	.... mg g^{-1}					
1999 1st sampling						
Control	37.0 a	4.25 a	29.7 a	4.60 a	1.90 a	1.24 a
100 kg ha^{-1} S	38.6 a	4.10 a	28.6 a	4.42 a	1.65 a	1.24 a
1999 2nd sampling						
Control	36.6 a	4.40 a	30.9 a	4.03 a	2.40 a	1.24 a
100 kg ha^{-1} S	38.1 a	4.50 a	32.5 a	4.38 a	2.20 a	1.35 a
2000 1st sampling						
Control	44.9 a	6.23 a	35.0 a	4.50 a	2.43 a	1.44 a
100 kg ha^{-1} S	47.1 a	5.90 a	34.5 a	4.60 a	1.67 a	1.28 a
	NO_3-N	**SO_4-S**	**Fe**	**Mn**	**Zn**	**Cu**
	.... µg g^{-1}					
1999 1st sampling						
Control	228 a	137 a	54.5 a	18.1 a	49.2 a	8.94 a
100 kg ha^{-1} S	267 a	144 a	62.6 a	21.9 a	57.1 a	6.31 a
1999 2nd sampling						
Control	206 a	66.8 a	61.0 a	19.4 a	49.1 a	9.68 a
100 kg ha^{-1} S	311 a	38.6 a	66.4 a	24.8 a	49.2 a	7.71 a
2000 1st sampling						
Control	839 b	84.6 a	74.0 a	15.4 a	57.7 a	8.96 a
100 kg ha^{-1} S	431 a	74.1 a	70.2 a	20.3 a	67.1 a	10.27 a

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test)

The fourth field trial was carried out at the experimental site in Alt Mölln (Schleswig-Holstein) in 2001 with the cultivar *Ariane*. 100 kg ha^{-1} S was applied on 27 March. Spear and fern samples were taken on 15 May and 7 September, respectively. In table 3-17 the results of the chemical analysis are summarized. S fertilization increased S content in asparagus spears and fern of the cultivar *Ariane* by 1.74 mg g^{-1} and 0.62 mg g^{-1}, respectively. Comparing this data with the results from the field trials in Braunschweig, it could be shown that spring application of S resulted in distinctly higher response than autumn applications (Table 3-14 and 3-17). The SO_4-S content increased approximately by the same extent so that apparently more S was organically bound on the test site in Alt Mölln. The concentration of SO_4-S in spears and fern of the cultivar *Ariane* was 35.3 µg g^{-1} and 37.7 µg g^{-1} higher in plots supplied with S fertilization than the control (Table 3-17). All other nutrients with the exception of Fe in fern were not statistically significant affected by S fertilization (Table 3-17).

Table 3-17: Effect of sulfur fertilization on the mineral content of asparagus spears and fern (cultivar *Ariane* grown at Alt Mölln in 2001).

Treatment	**N**	**P**	**K**	**S**	**Ca**	**Mg**
	mg g^{-1}					
Spears						
Control	49.4 a	6.97 a	41.7 a	5.56 a	3.33 a	1.53 a
100 kg ha^{-1} S	51.9 a	7.37 a	38.1 a	7.30 b	3.40 a	1.68 a
Fern						
Control	35.2 a	2.37 a	28.1 a	4.58 a	10.6 a	3.11 a
100 kg ha^{-1} S	36.9 a	2.47 a	28.0 a	5.20 b	11.6 a	3.09 a
	NO_3-N	**SO_4-S**	**Fe**	**Mn**	**Zn**	**Cu**
	µg g^{-1}					
Spears						
Control	536 a	76.5 a	54.3 a	13.0 a	67.1 a	23.3 a
100 kg ha^{-1} S	625 a	112 b	62.5 a	13.0 a	70.0 a	32.2 a
Fern						
Control	353 a	277 a	79.5 a	33.1 a	13.1 a	8.35 a
100 kg ha^{-1} S	261 a	315 b	126 b	40.8 a	14.4 a	9.28 a

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test)

The cultivar *Ariane* grown at the experimental site in Alt Mölln had the highest mean of the N, P, K, S, Ca and Mg content with 51.2 mg g^{-1}, 7.2 mg g^{-1}, 39.4 mg g^{-1}, 6.5 mg g^{-1}, 3.4 mg g^{-1} and 1.6 mg g^{-1}, respectively. But it had also the lowest Mn content with 13.0 µg g^{-1} and the highest NO_3-N content with an average 580 µg g^{-1}, while the cultivar *Rekord* grown at the experimental site in Veltenhof had the lowest NO_3-N with an average 181 µg g^{-1} The cultivar *Huchels Alpha* grown at the experimental site in Rietze had the highest Fe and SO_4-S content with 80.8 µg g^{-1} and 118 µg g^{-1}, respectively.

It was found also that the cultivar *Ariane* grown in the crop performance trial in Burgwedel, Lower Saxony had 183 µg g^{-1} more SO_4-S content than the same cultivar grown at Alt Mölln, Schleswig-Holstein. Similar results was found with the cultivar *Huchels Alpha*.

3.3.2 Organic compounds

At a low S supply relatively more of the S taken up by the plant is incorporated into organic compounds (Mengel, 1991). With increasing S supply and absorption the ratio organic:inorganic S in plants decrease (Mengel, 1991). Once the demand for organic S has been satisfied the content of inorganic S increases (Mengel, 1991).

As shown in Figures 3-9, 3-10, 3-11 and 3-12 S fertilization increased the protein content of all cultivars, but differences were statistically not significant. It was also shown that the protein content in spears of *Huchels Alpha* and *Schwetzinger Meisterschuss* was higher in the second years (Third sampling) than in the first year of experimentation.

The effect of S fertilization on the cysteine content is presented in table 3-18. Data show that S fertilization significantly increased the cysteine content in spears of the cultivars *Rekord* and *Schwetzinger Meisterschuss*. In case of the cultivars *Ariane* and *Huchels Alpha* S fertilization had no significant influence on the cysteine content, but the concentration was tendentiously increased by the treatment. The table reveal also that when the initial cysteine content is already low, S fertilization increases the cysteine content (Fig. 3-8).

As shown in Fig. 3-13 S fertilization increased the glutathione content of all asparagus cultivars, but the differences were statistically not significant. In studies with other crops it was shown that S supply had a significant positive effect on the glutathione content (De Kok et al., 1981; Schnug et al., 1995).

Table 3-18: Effect of sulfur fertilization on the cysteine (µmol g^{-1} dw) content of the cultivars Ariane (2001), Huchels Alpha, Schwetzinger Meisterschuss and Rekord (1999).

Sulfur fertilization (site)	Ariane (Alt Mölln)	Huchels Alpha (Rietze)	S. Meisterschuss (Gross Schwülper)	Rekord (Veltenhof)
Control	6.68 a	5.60 a	3.94 a	4.70 a
100 kg ha^{-1} S	7.23 a	5.96 a	5.67 b	6.92 b

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test)

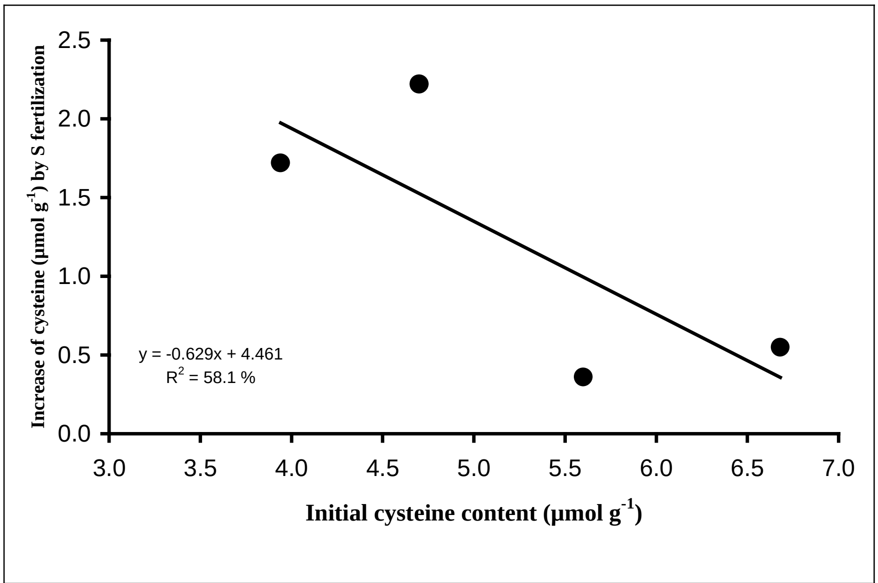

Fig. 3-8: Relationship between initial cysteine in spears and its increasing as affected by S fertilization

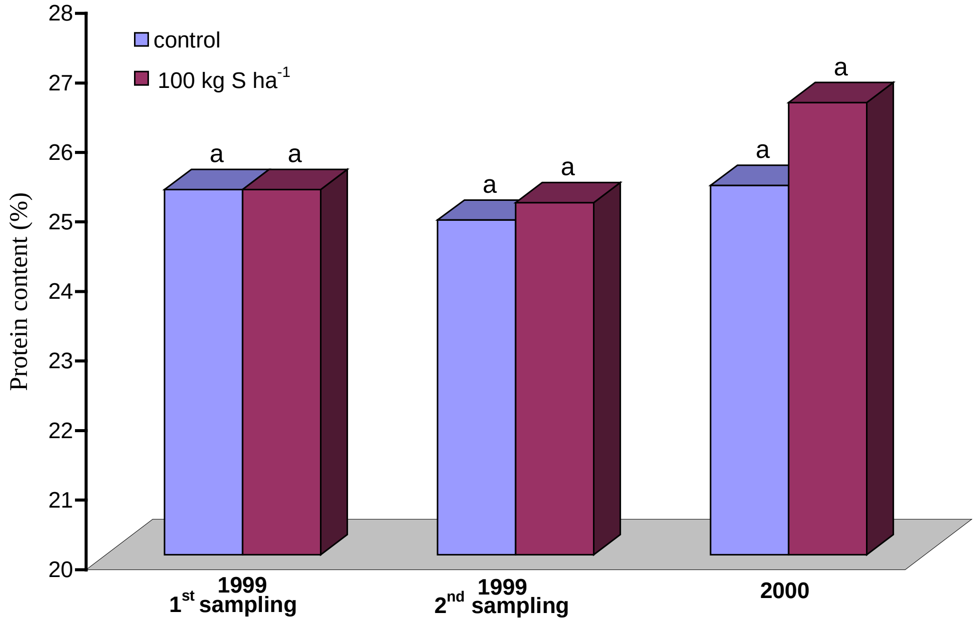

Fig. 3-9: Effect of sulfur fertilization on the protein content of spears of the cultivar *Huchels Alpha* grown at the experimental site in Rietze in 1999 and 2000 (means compared by the Tukey´s test)

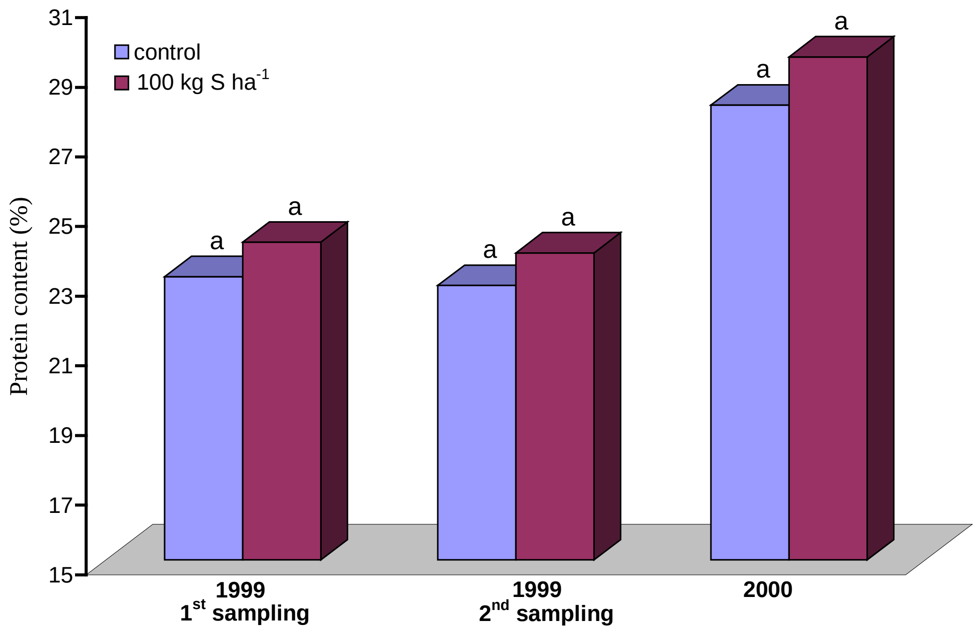

Fig. 3-10: Effect of sulfur fertilization on the protein content of spears of the cultivar *Schwetziner Meisterschuss* grown at the experimental site in Gross Schwülper in 1999 and 2000 (means compared by the Tukey´s test)

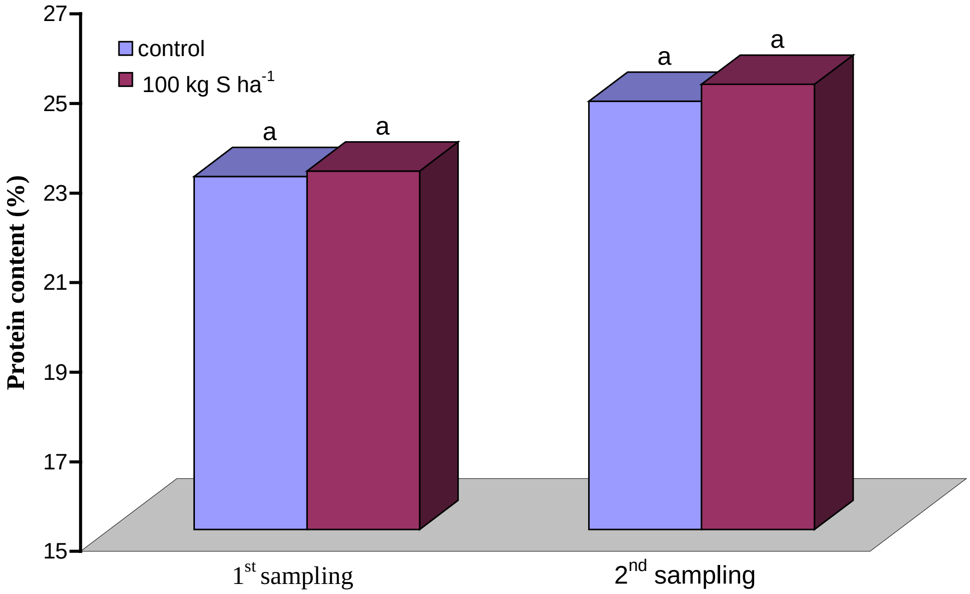

Fig. 3-11: Effect of sulfur fertilization on the protein content of the cultivar *Rekord* grown the experimental site in Veltenhof in 1999 (means compared by the Tukey´s test)

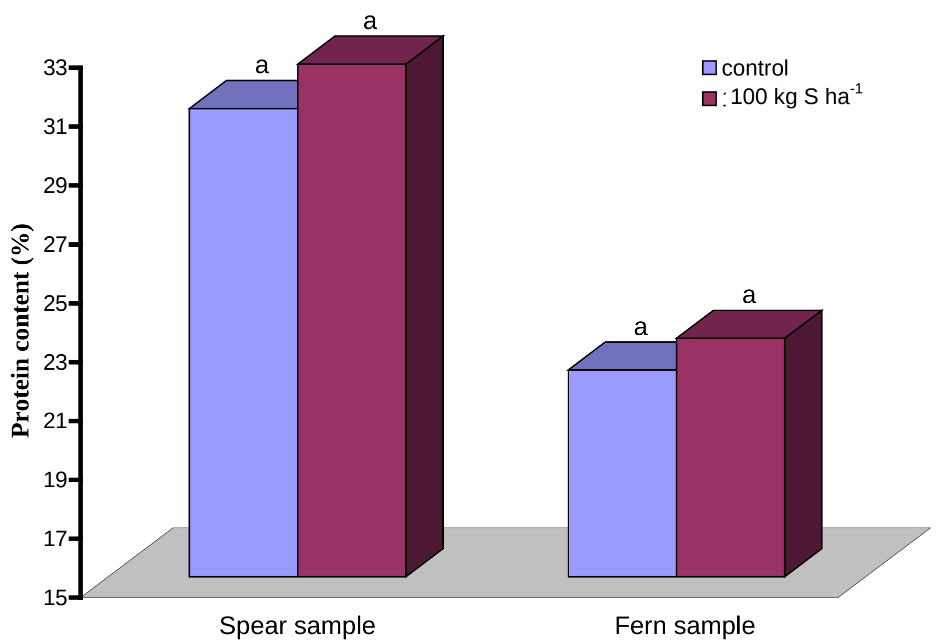

Fig. 3-12: Effect of sulfur fertilization on the protein content of the cultivar Ariane grown at the experimental site in Alt Mölln in 2001 (means compared by Tukey´s test)

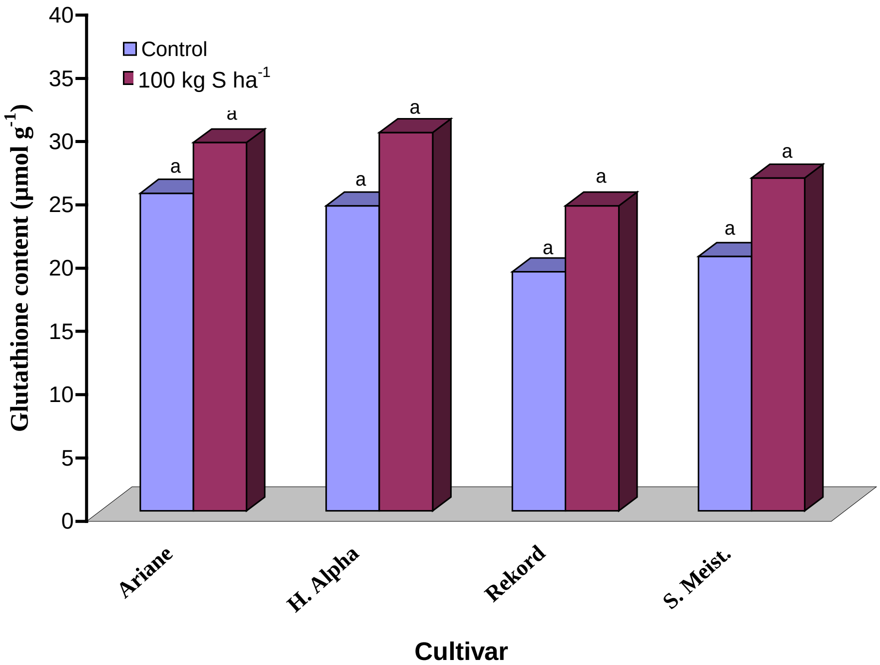

Fig. 3-13: Effect of sulfur fertilization on the glutathione content of asparagus spear in the cultivars *Ariane*, *Huchels Alpha*, *Rekord* and *Schwetzinger Meisterschuss* grown at different location in Lower Saxony and and Schlwswig-Holstein (means compared by Tukey´s test)

The results from the sulfur fertilization trials (chapter 3.3) can be summarized as follows:

1. S fertilization had a significant influence on the S and SO_4-S content of spears of the cultivars *Ariane*, *Huchels Alpha* and *Rekord* but the differences in the S and SO_4-S content was not significant for the cultivar *Schwetziner Meisterschuss*.
2. S fertilization significantly decreased NO_3-N content of the cultivar *Schwetzinger Meisterschuss* grown in Gross Schwülper in the second year.
3. The glutathione content of all cultivars increased by S fertilization but differences proved to be statistically not significant.
4. The protein content of all cultivars and the cysteine content of the cultivars *Ariane* and *Huchels Alpha* were not significantly affected by S fertilization. The cysteine content of the cultivars *Rekord* and *Schwetzinger Meisterschuss* significantly increased by sulfur fertilzation.

3.4 Influence of nitrogen and sulfur fertilization on growth and chemical composition of asparagus transplants

The use of asparagus seedling transplants grown in greenhouse is an important method in asparagus reproduction (Benson et al., 1978). Optimum plant growth of the asparagus seedlings is a prerequisite for an efficient production and reproduction of plants. Fisher and Benson (1983) studied the effect of the N and P supply on the growth of asparagus seedlings. They found that N and P supply increased shoot dry weight by increasing the number of shoots. The present experiment was conducted in order to study the effect of an increasing nitrogen and sulfur supply on shoot and root growth as well as the mineral nutritional status of transplants in two asparagus cultivars (*Huchels Alpha* and *Hannibal*). The investigations were conducted at limited and sufficient level of N and S.

3.4.1 Vegetative growth

The effect of N and S fertilization on the vegetative growth is presented in table 3-19. The data show that the N supply significantly influenced plant height, fresh and dry weight of both cultivars. The highest level of N gave the highest value of all recorded parameters for both cultivars. Fisher and Benson (1983) found that N increased shoot number and the mean dry weight of shoots; a low level of nitrogen was an important limiting factor to plant growth.
The cultivar *Hannibal* produced a higher number of shoots and fresh and dry weight than the cultivar *Huchels Alpha* (Table 3-19). Also, the differences between S levels were significant for the all vegetative parameters of both cultivars except for the number of shoots of the cultivar *Hannibal*. Generally the number of shoots, plant height, fresh and dry weight increased with increasing S fertilization from 1 mg S to 25 mg S per plant (Table 3-19).

The results from the analysis of variance (Table 3-19) reveal that the two cultivars, *Huchels Alpha* and *Hannibal* showed significant differences for the parameters fresh and dry weight of both shoots and roots and the number of roots per plant (Table 3-19). In the experiment of Stein (1987) it was found that there were significant differences in the growth parameters among one American cultivar (*UC 72*) and two German cultivars (RB and EM) and three strains under field conditions in the first year after planting.

The interaction between N and S fertilization was significant for the number of shoots and root fresh weight, but the interaction between cultivar and S fertilization was only significant for plant height, fresh and dry weight of shoots and root.

Table 3-19: Influence of nitrogen and sulfur fertilization on the vegetative growth of transplants of two asparagus cultivars in a pot experiment with increasing N and S supply.

Treat-ment	**Huchels Alpha**				**Hannibal**			
	No. of shoots	Plant height (cm)	Shoots (fw) (g)	Shoots (dw) (g)	No. of shoots	Plant height (cm)	Shoots (fw) (g)	Shoots (dw) (g)
Nitrogen supply (mg pot^{-1})								
250	5.8 a A	40.0 a A	8.4 a A	2.7 a A	6.5 a A	41.3 a A	11.6 a B	3.4 a A
500	7.2 a A	50.7 b B	10.7 b A	3.2 b A	7.9 b A	45.2 b A	12.8 b A	3.7 a A
Sulfur supply (mg pot^{-1})								
1	5.1 a A	40.4 a A	6.8 a A	2.3 a A	6.8 a B	40.6 a A	11.6 a B	3.0 a B
5	6.9 bcA	46.1 abA	9.0 b A	2.7 a A	7.1 a A	43.9 abA	12.8 abB	3.6 b B
25	7.3 cA	49.6 b B	13.0 c A	3.9 b A	7.6 a A	45.4 b A	13.2 bA	4.1 c A

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test); capital letters for significant differences between cultivars

3.4.2 Root growth

The influence of N and S fertilization on root growth parameters such as number of roots, root length, number of buds and root fresh and dry weight per plant was also investigated. The results from the analysis of variance showed that differences between nitrogen levels were significant for the number of buds and root fresh weight of the cultivar *Huchels Alpha* and for the number of roots and root fresh and dry weight of the cultivar *Hannibal* (Table 3-20). The results are in line with those of Fisher and Benson (1983) who found that 100 mg l^{-1} N increased both shoot and root growth as well as total dry weight of the cultivar *UC157* grown in peat : vermiculite medium.

Data presented in table 3-20 show that S fertilization increased the number of roots per plant, number of buds per plant and root fresh and dry weight per plant of both cultivars. The data in table 3-19 and 3-20 show that shoot and root growth of the cultivar *Hannibal* was higher than that of the cultivar *Huchels Alpha*.

The results reveal that the mediate application rates of 250 mg pot^{-1} N and 5 mg pot^{-1} S were not sufficient to satisfy the nutrient demand. For optimum root and shoot growth the highest S application rate of 25 mg pot^{-1} and N rate of 500 mg pot^{-1} was required. This suggests that growth of asparagus transplants would be further improved by increase nutrient supply.

Table 3-20: Influence of nitrogen and sulfur fertilization on root growth of transplants of two asparagus cultivars in a pot experiment with increasing N and S supply.

Treat-ment	**Huchels Alpha**					**Hannibal**				
	No. of roots	No. of buds	Root length (cm)	Roots (fw) (g)	Roots (dw) (g)	No. of roots	Buds No.	Root length (cm)	Roots (fw) (g)	Roots (dw) (g)
Nitrogen supply (mg pot^{-1})										
250	33.6 a A	12.1 a A	37.7 a A	97.9 a A	19.2 a A	35.9 a B	12.1 a A	39.2 a A	105.0 a B	21.9 a A
500	38.1 a A	14.7 b A	42.3 a A	108.2 b A	21.0 a A	48.0 b B	14.7 b A	42.2 a A	121.0 b B	26.3 b B
Sulfur supply (mg pot^{-1})										
1	31.1 a A	12.3 a A	39.5 a A	92.8 a A	17.2 a A	40.3 a B	14.1 a A	37.5 a A	104.5 a B	21.2 a B
5	33.6 a A	12.6 a A	41.9 a A	97.3 a A	19.1 a A	42.3 a B	14.0 a A	39.3 a A	114.7 b B	25.2 b B
25	42.8 b A	15.4 b A	38.5 a A	118.9 b A	24.0 b A	43.4 a A	14.6 a A	40.7 a A	120.1 b A	25.8 b A

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test); capital letters for significant differences between cultivars

3.4.3 Mineral nutrient content

The macro- and micro-nutrient content in the shoots of both asparagus cultivars was not significantly affected by increasing nitrogen levels with the exception of the total N content, which increased with increasing N fertilization (Table 3-21). Similar results were determined for the elemental concentrations in roots (Table 3-22). N fertilization increased N content in shoots and roots of the cultivar *Huchels Alpha* by 4.3 mg g^{-1} and 4.7 mg g^{-1} while in the cultivar *Hannibal* N fertilization increased N content in the shoots and roots only by 0.30 mg g^{-1} and 2.4 mg g^{-1}, respectively (Table 3-21 and 3-22).

The analysis of variance showed that differences between cultivars existed for P and Mg in shoots and Fe and Mn in roots in depended on the N supply. The interaction between N and S fertilization was significant for the N, P, S, Ca and Cu content of asparagus shoots and for the NO_3-N and P content of asparagus roots.

Table 3-21: Influence of nitrogen fertilization on the mineral content in shoots of transplants of two asparagus cultivars in a pot experiment with increasing N and S supply.

N supply mg pot^{-1}	N	P	K	S	Ca	Mg	Fe	Mn	Zn	Cu
	..............................mg g^{-1}						.... µg g^{-1}			
Huchels Alpha										
250	16.2 a A	2.10 a B	23.3 a A	1.66 aA	14.7 aA	1.66 aB	160 aA	210 aA	18.2 aA	8.66 aA
500	20.5 b A	2.15 a B	23.0 a A	1.81 aA	14.8 aA	1.77 aB	147 aA	234 aA	18.4 aA	7.73 aA
Hannibal										
250	19.0 aB	1.77 aA	23.7 aA	1.52 aA	16.6 aA	1.50 aA	136 aA	209 aA	19.3 aA	8.76 aA
500	19.3 aA	1.66 aA	22.4 aA	1.78 aA	16.5 aA	1.48 aA	132 aA	230 aA	20.8 aA	9.81 aA

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test); capital letters for significant differences between cultivars

Table 3-22: Influence of nitrogen fertilization on the mineral content in roots of transplants of two asparagus cultivars in a pot experiment with increasing N and S supply.

N supply mg pot^{-1}	N	P	K	S	Ca	Mg	Fe	Mn	Zn	Cu
	.... mg g^{-1}						.... µg g^{-1}			
Huchels Alpha										
250	6.3 aA	1.89 aA	17.6 aA	0.57 aA	2.6 aA	1.07 aA	813 aB	102 aB	10.5 aA	11.2 aA
500	11.0 bA	2.25 bA	18.7 aA	0.63 aA	2.9 aA	1.08 aA	973 aB	128 aB	16.1 aA	12.7 aA
Hannibal										
250	7.0 aA	1.96 aA	17.1 aA	0.51 aA	2.64 aA	1.03 aA	586 aA	98.2 aA	10.2 aA	8.7 aA
500	9.4 bA	2.07 aA	18.2 aA	0.51 aA	2.98 aA	1.10 aA	584 aA	91.4 aA	11.3 aA	12.7 aA

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test); capital letters for significant differences between cultivars

The influence of S fertilization on the mineral content of shoots and roots of the transplants of both asparagus cultivars is shown in table 3-23 and 3-24. The data show that the differences between S levels were significant for the N and S content in the shoots of both cultivars, but there was no significant difference between the levels 5 mg and 25 mg.

The N content in roots of both cultivars was significantly affected by increasing S levels. S fertilization affected the Mn content in the shoots of the cultivar *Huchels Alpha* and the Fe content of the cultivar *Hannibal*. The micro-nutrient content and P, K, S, Ca and Mg concentrations in the roots of both cultivars were not significantly affected by increasing S levels. In this study the concentration of S in shoots and roots of both cultivars was lower than as found by Paine and Harrison (1994) in the cultivar *Syn 4-56* grown in washed sand under greenhouse conditions, which was 2.6 mg g^{-1} in shoots and 1.6 mg g^{-1} in the roots. This could be due to the difference in plant age because the mineral content in the study of Paine and Harrison (1994) it was after eight weeks while in this experiment was determined after 20 weeks but the Mn and Fe content was higher than 60 µg g^{-1} and 134 µg g^{-1} in shoots and 58 µg g^{-1} and 302 µg g^{-1} in the roots found by the same authors. The P, K and Cu content was in the same line with those found by Paine and Harrison (1994).

Table 3-23: Influence of sulfur fertilization on the mineral content in shoots of transplants of two asparagus cultivars in a pot experiment with increasing N and S supply.

S supply mg pot^{-1}	**N**	**P**	**K**	**S**	**Ca**	**Mg**	**Fe**	**Mn**	**Zn**	**Cu**
	mg g^{-1}						**µg g^{-1}**			
Huchels Alpha										
1	18.2 aA	2.15 aB	21.9 aA	1.51 aA	14.3 aA	1.66 aA	172 aB	253 bA	18.6 aA	9.33 aA
5	17.7 aA	2.20 aB	23.5 aA	1.70 bA	15.1 aA	1.63 aA	143 aA	223 abA	16.2 aA	7.91 aA
25	19.2 bA	2.03 aA	22.2 aA	1.99 bA	14.8 aA	1.85 aA	146 aA	190 aA	19.1 aA	7.37 aA
Hannibal										
1	18.6 aA	1.65 aA	21.7 aA	1.58 aA	17.1 aA	1.51 aA	106 aA	213 aA	18.2 aA	8.76 aA
5	19.3 bB	1.56 aA	23.4 aA	1.66 bA	16.4 aA	1.46 aA	148 bA	217 aA	20.1 aA	10.1 aA
25	19.5 bA	1.92 aA	24.1 aA	1.72 bA	16.2 aA	1.50 aA	148 bA	230 aB	21.3 aA	8.93 aA

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test); capital letters for significant differences between cultivars

Table 3-24: Influence of sulfur fertilization on the mineral content in roots of transplants of two asparagus cultivars in a pot experiment with increasing N and S supply.

S supply mg pot^{-1}	**N**	**P**	**K**	**S**	**Ca**	**Mg**	**Fe**	**Mn**	**Zn**	**Cu**
	mg g^{-1}						**µg g^{-1}**			
Huchels Alpha										
1	11.4 bB	2.22 aB	19.1 aA	0.52 aA	2.95 aA	1.12 aA	861 aB	106 aB	12.2 aA	10.2 aA
5	10.6 bB	2.24 aB	19.2 aA	0.57 aA	2.79 aA	1.09 aA	897 aB	111 aB	11.3 aA	11.3 aA
25	6.9 aA	1.75 aA	16.2 aA	0.71 aA	2.58 aA	1.00 aA	920 aB	129 aB	16.1 aA	14.8 aA
Hannibal										
1	5.77 aA	1.74 aA	16.4 aA	0.56 aA	2.79 aA	1.06 aA	528 aA	93.2 aA	8.5 aA	8.0 aA
5	7.73 bA	1.95 aA	17.6 aA	0.48 aA	2.80 aA	1.05 aA	550 aA	89.4 aA	11.2 aA	10.2 aA
25	11.0 cB	2.35 bB	19.0 aA	0.50 aA	2.84 aA	1.09 aA	677 aA	102 aA	13.1 aA	15.1 aA

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test); capital letters for significant differences between cultivars

The effect of N fertilization on the protein, NO_3-N and SO_4-S content in asparagus shoots and roots of both cultivars is presented in table 3-25. The data show that protein, NO_3-N and SO_4-S content in shoots and roots of transplants of the cultivar *Huchels Alpha* increased significantly with the N levels (Table 3-25). The NO_3-N content in the shoots and protein content in the roots of the cultivar *Hannibal* increased significantly by N fertilization but SO_4-S in the shoots and roots of the same cultivar was not significantly affected by N fertilization (Table 3-25).

Data presented in table 3-26 show that S fertilization significantly increased the protein, NO_3-N and SO_4-S content in shoots of *Huchels Alpha*, while for the cultivar *Hannibal* the effect was only significant for protein and NO_3-N. Striking is in this context that the cultivar *Hannibal* had more than two times higher SO_4-S contents in the shoots than *Huchels Alpha*. In the roots, *Huchels Alpha* showed higher SO_4-S content than *Hannibal*. In the roots of both asparagus cultivars S fertilization significantly increased the protein content (Table 3-26). Both asparagus cultivars showed differences in the tendency for accumulation of SO_4.

Table 3-25: Influence of nitrogen fertilization on protein, nitrate and sulfate content in shoots and roots of transplants of two asparagus cultivars in a pot experiment with increasing N and S supply.

N supply mg pot^{-1}	Huchels Alpha			Hannibal		
	Protein %	**NO_3-N µg g^{-1}**	**SO_4-S µg g^{-1}**	**Protein %**	**NO_3-N µg g^{-1}**	**SO_4-S µg g^{-1}**
Shoots						
250	10.2 a A	124 a A	3.28 a A	11.87 a B	119 a A	12.8 a B
500	12.6 b A	156 b A	6.65 b A	12.05 a A	183 b A	11.5 a B
Roots						
250	3.94 a A	117 a A	1.10 a A	4.31 a A	195 a B	1.03 a A
500	8.10 b B	258 b A	2.09 b B	5.85 b A	219 a A	1.06 a A

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test); capital letters for significant differences between cultivars

Table 3-26: Influence of sulfur fertilization on the protein, nitrate and sulfate content in shoots and roots of transplants of two asparagus cultivars in a pot experiment with increasing N and S supply.

S supply mg pot^{-1}	Huchels Alpha			Hannibal		
	Protein %	NO_3-N µg g^{-1}	SO_4-S µg g^{-1}	Protein %	NO_3-N µg g^{-1}	SO_4-S µg g^{-1}
Shoots						
1	10.8 a A	106 a A	5.18 a A	11.6 a A	112 a A	13.3 a B
5	11.3 ab A	154 b A	3.16 abA	12.1 b A	173 b A	12.2 a B
25	12.0 b A	160 b A	6.42 b A	12.2 b A	169 b A	10.0 a B
Roots						
1	4.3 a A	182 a A	1.80 a B	3.60 a A	157 a A	0.58 a A
5	6.6 b B	188 a A	1.93 a B	4.83 b A	228 a B	1.19 a A
25	7.1 b A	192 a A	1.10 a B	6.81 c A	237 a B	0.83 a A

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test); capital letters for significant differences between cultivars

The relationship between chemical constituents in shoots and that in roots of the two asparagus cultivars was also investigated. There was a significant relationship between the P and N content in shoots and that in roots of the cultivars *Huchels Alpha* and *Hannibal* (Fig. 3-14 and 3-15). There was also significant relationship between N, P and K content in roots of the cultivar *Huchels Alpha* and only between N and P in roots of the cultivar *Hannibal*. While for all other nutrients no significant relationship was found (see appendix Fig. 7-2).

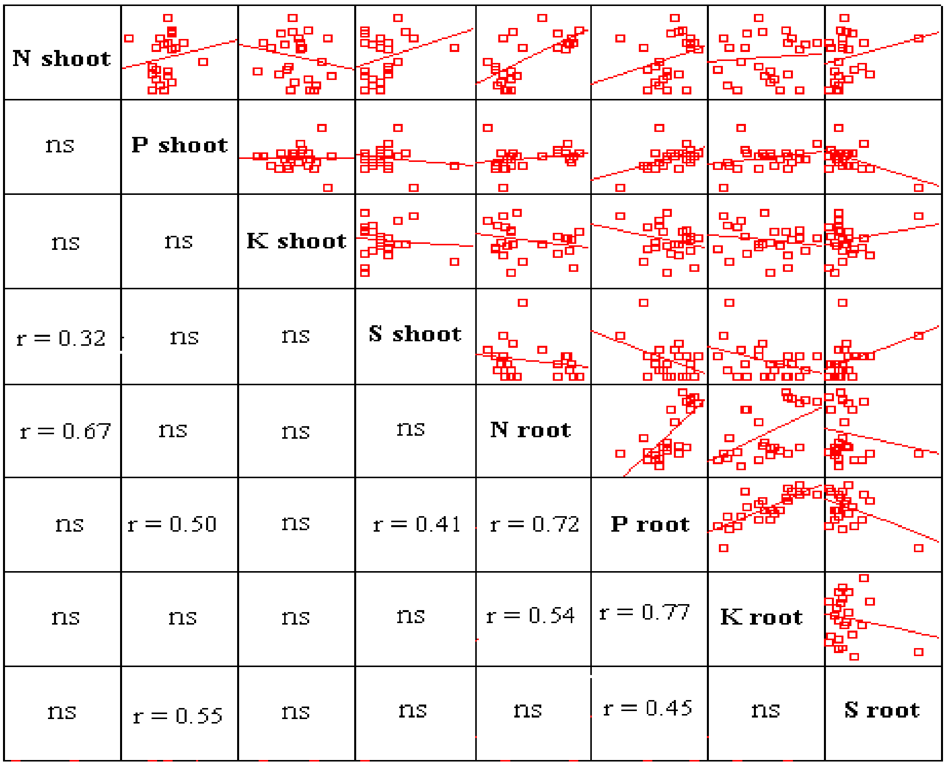

Fig. 3-14: Correlation matrix for plant nutrient concentration (N, P, K and S) in shoots and roots of transplant of the cultivar Huchels Alpha grown in pots.

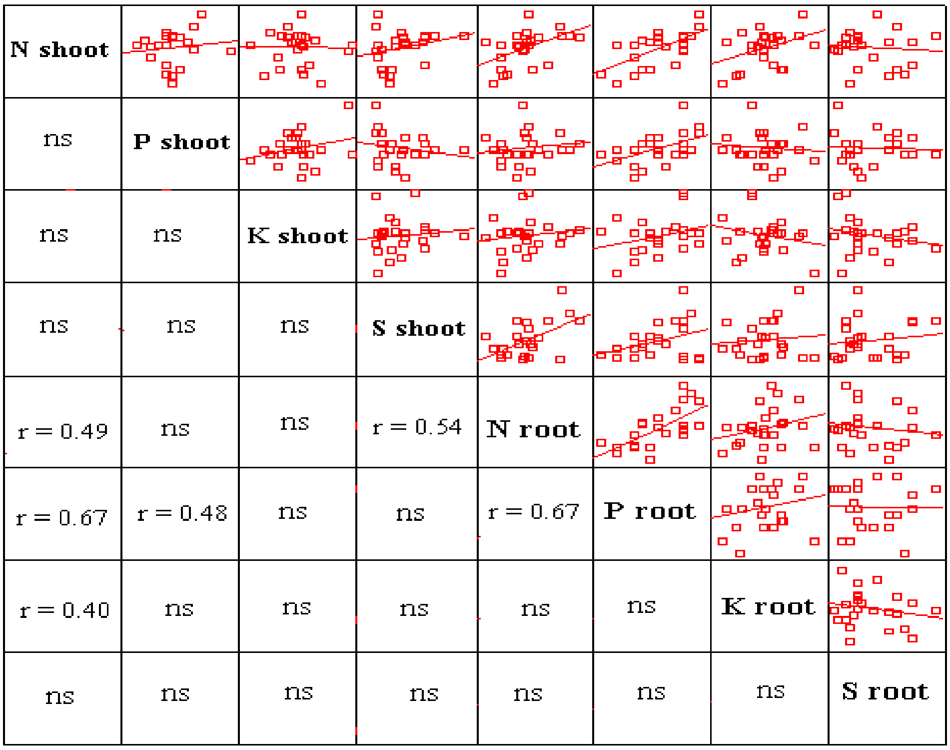

Fig. 3-15: Correlation matrix for plant nutrient concentration (N, P, K and S) in shoots and roots of transplant of the cultivar Hannibal grown in pots.

Summarizing this chapter, the pot experiment with asparagus transplants of two cultivars yielded the following results:

1- The N supply significantly increased plant height and fresh and dry weight of both cultivars and at the same time the N and NO_3-N content. The N supply had no effect on the nutritional composition of shoots in both cultivars.

2- The S supply increased all recorded vegetative growth parameters in both cultivars. S fertilization significantly increased the protein and SO_4-S content in shoots of the cultivar *Huchels Alpha*.

3- The cultivar *Hannibal* produced a higher number of shoots and fresh and dry weight than the cultivar *Huchels Alpha*.

3.5 Relation between N and S nutrition and composition of asparagus spears and fern

Asparagus is a plant with an extended root system. Common pot experiments in pots like Mitscherlich thus seem not to be adequate to investigate the behavior of the plants under natural conditions. Therefore this experiment was conducted in large pots with ample space for the plant to develop its root system in order to study the influence of N and S supply on yield and spear quality parameters as well as the chemical composition of spears and fern. One year old crowns of the cultivar *Hannibal* were cultivated in large pots, one plant per pot, and treated with two nitrogen levels (1.125 g N or 2.25 g N pot^{-1}) and three levels of sulfur (75, 225 or 450 mg S pot^{-1}).

3.5.1 Influence of N and S fertilization on yield parameters of asparagus in large pot trial

Asparagus is a vegetable of great nutritional and economic importance because of its high dietary value and its availability at a time of the first half of year when there is a shortage of fresh vegetable on the market (Pinkau and Krutz, 1985). In all plants, N is a constituent of chlorophyll, protein including the enzymes and many other compounds. A lack of N causes chlorosis yellow and stunned growth, but with an adequate supply of nitrogen, vegetative growth is rapid and foliage dark green in color (Olsen and Kurtz, 1982). N as a plant nutrient is treated in a great number of publications. This indicates not only the importance of N in the physiology of plants, but also the difficulty of establishing critical levels for its use for every species (Jones, 1966). In commercial production, it is the element most likely to be deficient. In the physiology of the plant, it is a very mobile element, entering many metabolic components (Jones, 1966).

Data presented in table 3-27 reveal that the number of main shoots and plant height were not significantly affected by increasing N and S rates during all the two years of experimentation. Plant height was significantly higher in the second year than in the first year. This explain why the spear yield was significantly higher in the second harvest year than the first harvest one.

Table 3-27: Influence of nitrogen and sulfur fertilization on the number of main shoots and plant height of the cultivar *Hannibal* grown in a large pot experiment.

Treatment	No. of main shoots	Plant height (cm)	No. of main shoots	Plant height (cm)
	2001		**2002**	
Nitrogen application (g pot^{-1})				
1.125	3.8 a	143 a	3.6 a	180 a
2.25	5.2 a	145 a	3.8 a	197 a
Sulfur application (mg pot^{-1})				
75	4.5 a	141 a	3.4 a	188 a
225	4.7 a	145 a	3.5 a	201 a
450	4.3 a	147 a	4.1 a	175 a

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test)

The analysis of variance (Table 3-28) showed that there was a significant interaction between N and S fertilization concerning the spear yield and spear number in the second harvest season. Data presented in table 3-29 show that N fertilization did not significantly affect parameters of asparagus yield in both of experimental years. Similar results were found by Warman (1991) and Paschold et al. (1999) who reported that N fertilization treatments did not significantly influence spear yield under field conditions. Makus (1995) found that N fertilization with 80 kg N per hectare had no effect on the number of green and white asparagus spears and yield per hectare in the year of application. In comparison, Brown and Carolus (1965) found, in a field experiment, a loose correlation between N application and yield.

Yield was significantly lower in the first harvest season than in the second harvest season. This was likely due to the limited storage of starch in the flashy roots to enable high spear yield in the small young crowns (Mullin and Swingle, 1979). Spear yield per plant was 13.8 g and 18.1 g higher in the pots which received 2.25 g N than plants received 1.125 g N per pot in the first and second harvest season, respectively (Table 3-29).

Table 3-28: ANOVA (F-test) for the effect of nitrogen and sulfur application on the yield parameters of the cultivar *Hannibal* grown in a large pot experiment in 2002 and 2003.

Source of variation	Yield plant^{-1} (g)	No. of spears plant^{-1}	Average spear wt (g)	Average spear diameter (mm)	Dry wt. (%)
2002					
Nitrogen (N)	ns	ns	ns	ns	ns
Sulfur (S)	ns	ns	ns	ns	ns
N x S	ns	ns	ns	ns	ns
2003					
Nitrogen (N)	ns	ns	ns	ns	ns
Sulfur (S)	*	*	ns	ns	ns
N x S	*	*	ns	ns	ns

* and ns: significant at 0.05 level and non significant

Table 3-29: Influence of nitrogen fertilization on different yield parameters of the cultivar *Hannibal* grown in a large pot experiment in 2002 and 2003.

N supply g pot^{-1}	Yield plant^{-1} (g)	No. of spears plant^{-1}	Average spear wt (g)	Average spear diameter (mm)	Dry wt. (%)
2002					
1.125	62.7 a	5.7 a	11.0 a	8.0 a	6.6 a
2.25	76.5 a	6.7 a	11.4 a	9.1 a	7.2 a
2003					
1.125	152 a	11.8 a	12.9 a	8.0 a	7.0 a
2.25	170 a	15.4 a	11.0 a	6.9 a	7.3 a

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test)

Very little is known about the effect of sulfur fertilization on asparagus yield and spears quality (Warman, 1991). In this experiment the S supply had no significant effect on the yield parameters, number of spears per plant, average spear weight, average spear diameter and spear dry weight in the first harvest season (Table 3-30).

In the second harvest season, spear number per plant significantly increased with increasing S supply (Table 3-30). 225 mg and 450 mg S per pot significantly increased the spears yield of asparagus in the second harvest season by 47.3 % in comparison with 75 mg S per pot. The difference between 225 mg and 450 mg S per pot was not statistically significant (Table 3-30).

The number of spears is usually twice as high in the second season of cultivation than in the first one, which is the reason for higher total spear yield in the second harvest season (Poll, 1995). Average spear weight and diameter did not differ in both seasons (Table 3-30).

Table 3-30: Influence of sulfur fertilization on yield parameters of the asparagus cultivar *Hannibal* grown in a large pot experiment in 2002 and 2003.

S supply mg pot^{-1}	Yield plant^{-1} (g)	No. of spears plant^{-1}	Average spear wt (g)	Average spear diameter (mm)	Dry wt. (%)
2002					
75	65.5 a	5.6 a	11.7 a	8.6 a	7.1 a
225	69.9 a	5.5 a	12.7 a	8.5 a	6.5 a
450	73.3 a	7.4 a	10.0 a	8.5 a	7.1 a
2003					
75	122 a	11.6 a	10.5 a	7.5 a	6.9 a
225	180 b	14.5 b	12.4 a	8.0 a	7.2 a
450	180 b	14.8 b	12.2 a	6.9 a	7.2 a

Numbers with different characters in the same column indicate statistically different mean at the 5% levels Tukey's test)

3.5.2 Influence of N and S fertilization on the chemical composition of asparagus spears and fern

3.5.2.1 Mineral nutrient content

The analysis of variance (F-test) showed that the interaction between N and S fertilization was significant only for the Mn and Cu content in asparagus spears in the second year (Table 3-31).

The effect of N fertilization on the chemical composition of asparagus spears in two harvest seasons is presented in table 3-32 and 3-33. The results reveal that N fertilization had a significant effect on Mn and Cu content in asparagus spears in the second harvest season. The content of NO_3-N and Mn was significantly lower in the second harvest season than in the first one (Table 3-33). Similar results were found by Makus (1995) who reported that N fertilization did not affect or reduce spear mineral content under field conditions. The same author found that the S, Ca and Cu content decreased and K concentration increased in spears within the harvest season. The fluctuation in mineral nutrient content of spears between the harvest seasons may be influenced by soil temperature and moisture (Makus, 1995).

Table 3-31: ANOVA (F-test) for the effect on nitrogen and sulfur application on the nutrient content in spears of the cultivar *Hannibal* grown in a large pot experiment in 2002 and 2003.

Source of variation	**N**	**P**	**K**	**S**	**Ca**	**Mg**	**Fe**	**Zn**	**Mn**	**Cu**	**NO_3-N**	**SO_4-S**
2002												
Nitrogen (N)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Sulfur (S)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns
N x S	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
2003												
Nitrogen (N)	ns	ns	ns	ns	ns	ns	ns	ns	*	*	ns	ns
Sulfur (S)	ns	ns	ns	ns	ns	ns	ns	ns	*	*	*	ns
N x S	ns	ns	ns	ns	ns	ns	ns	ns	*	*	ns	ns

* and ns: significant at 0.05 level and non significant

Table 3-32: Influence of nitrogen supply on the macro-nutrient content in spears of the cultivar *Hannibal* grown in a large pot experiment in 2002 and 2003.

N supply g pot^{-1}	**N**	**P**	**K**	**S**	**Ca**	**Mg**
	.. mg g^{-1}..					
2002						
1.125	29.7 a	3.89 a	23.2 a	3.07 a	2.04 a	0.99 a
2.25	30.1 a	3.81 a	23.4 a	3.21 a	1.87 a	0.98 a
2003						
1.125	3.23 a	4.64 a	26.3 a	3.07 a	2.08 a	1.07 a
2.25	3.40 a	4.69 a	27.4 a	3.22 a	2.02 a	1.05 a

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test)

Table 3-33: Influence of nitrogen supply on nitrate, sulfate and micro-nutrient content in spears of the cultivar *Hannibal* grown in a large pot experiment in 2002 and 2003.

N supply g pot^{-1}	**NO_3-N**	**SO_4-S**	**Fe**	**Mn**	**Zn**	**Cu**
	.... µg g^{-1}					
2002						
1.125	295 a	81.9 a	46.4 a	48.6 a	49.6 a	23.5 a
2.25	299 a	74.5 a	46.7 a	44.8 a	53.1 a	27.8 a
2003						
1.125	117 a	83.4 a	53.5 a	26.2 a	57.1 a	27.2 a
2.25	129 a	85.2 a	55.8 a	35.5 b	55.2 a	32.8 b

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test)

Data presented in table 3-34 and 3-35 show that S fertilization did not affect the chemical composition of asparagus spears in both harvest seasons with the exception of NO_3-N content, which reduced by sulfur fertilization. Generally, S is essential for the synthesis of proteins in plants. Under conditions of S deficiency, plants can not synthesize sufficient amounts of proteins and this means that N can accumulate in plant tissues in non-protein forms such as NO_3 (Schnug, 1997).

In the second harvest season, the highest S rate of 450 mg S per pot increased the Mn content and decreased the Cu concentrations (Table 3-35). Generally, the nutrient concentrations in spears were lower in large pot experiment than under field conditions (see table 3-1 and 3-2).

Table 3-34: Influence of sulfur supply on macro-nutrient content in spears of the cultivar *Hannibal* grown in a large pot experiment in 2002 and 2003.

S supply mg pot^{-1}	N	P	K	S	Ca	Mg
	.... mg g^{-1}					
2002						
75	30.0 a	3.95 a	23.6 a	2.92 a	2.05 a	1.00 a
225	29.9 a	3.76 a	22.9 a	3.26 a	1.87 a	0.98 a
450	29.8 a	3.84 a	23.4 a	3.24 a	1.94 a	0.99 a
2003						
75	33.1 a	4.75 a	27.3 a	3.14 a	2.10 a	1.02 a
225	32.0 a	4.58 a	26.5 a	3.02 a	1.60 a	1.04 a
450	34.4 a	4.68 a	26.8 a	3.28 a	2.45 a	1.13 a

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test)

Table 3-35: Influence of sulfur supply on nitrate, sulfate and micro-nutrient content in spears of the cultivar *Hannibal* grown in a large pot experiment in 2002 and 2003.

S supply mg pot^{-1}	NO_3-N	SO_4-S	Fe	Mn	Zn	Cu
	.... µg g^{-1}					
2002						
75	402 b	67.5 a	43.2 a	46.4 a	48.9 a	26.5 a
225	336 a	82.6 a	40.6 a	47.6 a	51.3 a	25.6 a
450	323 a	84.5 a	55.9 a	46.3 a	53.8 a	24.7 a
2003						
75	122 ab	104 a	51.8 a	28.1 a	51.2 a	35.8 b
225	141 b	105 a	60.0 a	26.1 a	56.6 a	25.4 a
450	106 a	107 a	52.1 a	38.4 b	60.7 a	28.8 a

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test)

The analysis of variance showed that the interaction between N and S fertilization was significant for the S and Ca content in the first year and not significant for other nutrients and all nutrients content in asparagus fern in the second year (Table 3-36).

The effect of N fertilization on the chemical composition of asparagus fern is shown in table 3-37 and 3-38. The results reveal that the N, K, S, Ca, Mg and Zn content of asparagus fern in the first growth season and Mn in the second growth season were significantly affected by the N supply (Table 3-37 and 3-38). Warman (1991) found, in a field study, that N fertilization increased the fern tissue N content, but effects were not constant over time. Brasher (1958) found the following nutrient concentrations in the fern to be adequate for a high yielding asparagus crop: N 37.5 – 38.0 mg g^{-1}; P 2.0 – 2.3 mg g^{-1}; K 17.5 – 19.0 mg g^{-1}; Ca 15.0 – 15.4 mg g^{-1} and Mg 3.9 – 4.1 mg g^{-1}.

Table 3-36: ANOVA (F-test) for the effect of nitrogen and sulfur application on the nutrient content in fern of the cultivar *Hannibal* grown in a large pot.

Source of variation	**N**	**P**	**K**	**S**	**Ca**	**Mg**	**Fe**	**Zn**	**Mn**	**Cu**	**NO_3-N**	**SO_4-S**
						2001						
Nitrogen (N)	*	ns	*	*	*	*	ns	*	ns	ns	ns	ns
Sulfur (S)	ns	ns	ns	*	*	ns	ns	ns	ns	*	*	*
N x S	ns	ns	ns	*	*	ns	ns	ns	ns	ns	ns	ns
						2002						
Nitrogen (N)	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns
Sulfur (S)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
N x S	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

* and ns: significant at 0.05 level and non significant

Table 3-37: Influence of nitrogen supply on the macro-nutrient concentration of fern of the cultivar *Hannibal* grown in a large pot experiment.

N supply g pot^{-1}	**N**	**P**	**K**	**S**	**Ca**	**Mg**
			mg g^{-1}			
			2001			
1.125	27.2 a	2.54 a	41.0 b	4.92 b	3.37 a	3.05 a
2.25	32.1 b	2.50 a	32.3 a	4.28 a	9.37 b	3.68 b
			2002			
1.125	23.8 a	2.33 a	25.2 a	3.5 a	6.91 a	2.17 a
2.25	23.9 a	2.39 a	26.0 a	3.6 a	7.29 a	2.13 a

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test)

Table 3-38: Influence of nitrogen supply on nitrate, sulfate and micro-nutrient concentration in fern of the cultivar *Hannibal* grown in a large pot experiment.

N supply g pot^{-1}	NO_3-N	SO_4-S	Fe	Mn	Zn	Cu
	..........µg g^{-1}..........					
2001						
1.125	203 a	382 b	145 a	314 a	29.0 a	23.1 a
2.25	191 a	218 a	147 a	320 a	33.0 b	20.3 a
2002						
1.125	55.2 a	241 a	73.4 a	206 a	32.9 a	14.0 a
2.25	55.6 a	267 a	86.4 a	239 b	35.8 a	17.4 a

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test)

S fertilization significantly affected S, Ca, NO_3-N, SO_4-S and Cu content of asparagus fern in the first year of cultivation. But differences were not statistically significant for the second year (Table 3-39 and 3-40). The macro- and micro-nutrient concentration was within the same range as found by Krarup (1990) in a field study with the cultivar UC 72.

Table 3-39: Influence of sulfur supply on the macro-nutrient content in fern of the cultivar *Hannibal* grown in a large pot experiment.

S supply mg pot^{-1}	N	P	K	S	Ca	Mg
	.... mg g^{-1}					
2001						
75	29.5 a	2.45 a	37.7 a	4.18 a	3.24 a	3.10 a
225	30.4 a	2.61 a	36.2 a	4.76 b	7.80 b	3.53 a
450	29.2 a	2.5 a	35.9 a	4.86 b	8.06 b	3.46 a
2002						
75	23.9 a	2.35 a	26.7 a	3.55 a	6.64 a	2.14 a
225	23.7 a	2.37 a	24.8 a	3.41 a	7.09 a	2.21 a
450	23.9 a	2.31 a	25.3 a	3.59 a	7.57 a	2.10 a

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test)

Table 3-40: Influence of sulfur supply on nitrate, sulfate and the micro-nutrient content in fern of the cultivar *Hannibal* grown in a large pot experiment.

S supply mg pot^{-1}	**NO_3-N**	**SO_4-S**	**Fe**	**Mn**	**Zn**	**Cu**
	.... µg g^{-1}..................					
2001						
75	1172 b	772 a	142 a	332 a	32.1 a	24.0 b
225	552 a	757 a	138 a	297 a	31.0 a	21.0 ab
450	894 ab	1219 b	158 a	324 a	30.3 a	19.1 a
2002						
75	259 a	777 a	75.7 a	218 a	34.6 a	15.6 a
225	235 a	694 a	79.8 a	227 a	34.3 a	17.3 a
450	241 a	814 a	84.2 a	223 a	34.3 a	14.1 a

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test)

3.5.2.2 Organic compounds

The influence of N and S fertilization on the protein and ascorbic acid content of asparagus spears is presented in table 3-41. An increasing N supply from 1.125 g to 2.25 g N per pot had no significant effect on the protein and ascorbic acid content in both years of experimentation. This compares to results by Makus (1995) who found in field study that protein content of white asparagus spears was also not affected by N fertilization. The cysteine content in the first season was affected by N fertilization but had no significant effect on cysteine content in the second season and glutathione content in both seasons (Table 3-42). The analysis of variance showed that the interaction between N and S was significant for ascorbic acid and cysteine content in the first season.

Increasing S supply from 75 mg to 450 mg S per pot, however, significantly increased the ascorbic acid content of asparagus spears in both seasons. In the first harvest season there was no significant difference between 225 mg and 450 mg S per pot (Table 3-41). Ojo and Oputa (1999) found, for celosia, that the S supply increased the SO_4-S and ascorbic acid content. Ojo and Oputa (1999) explain this by the fact that S enhances the photosynthetic carbon fixation. An increasing S supply had no significant effect on the protein content in both seasons (Table 3-41). Data in table 3-42 reveal that S fertilization had a significant effect on the glutathione content of spears in the second season and cysteine content in the first season. Schnug (1997) reported in this context that a significant relationship between S supply and S containing amino acids only exists under conditions of severe deficiency with visible symptoms.

Table 3-41: Influence of N and S fertilization on the protein and ascorbic acid content in spears of the cultivar Hannibal grown in a large pot experiment in 2002 and 2003.

Treatments	**Protein (% dw)**		**Ascorbic acid (mg 100 g^{-1} fw)**	
	2002	**2003**	**2002**	**2003**
N supply (g pot^{-1})				
1.125	18.6 a	20.2 a	19.1 a	16.7 a
2.25	18.8 a	21.3 a	19.9 a	18.9 a
S supply (mg pot^{-1})				
75	18.7 a	20.6 a	17.8 a	15.5 a
225	18.7 a	20.0 a	20.1 b	17.8 b
450	18.6 a	21.5 a	20.7 b	20.0 c
Nitrogen (N)	ns	ns	ns	ns
Sulfur (S)	ns	ns	*	*
N x S	ns	ns	*	ns

Numbers with different characters in the same column indicate statistically different mean at the 5% levels Tukey's test); * and ns: significant at 0.05 level and non significant

Table 3-42: Influence of N and S fertilization on the glutathione and cysteine content in spears of the cultivar *Hannibal* grown in a large pot experiment in 2002 and 2003.

Treatments	**Glutathione (µmol g^{-1})**		**Cysteine (µmol g^{-1})**	
	2002	**2003**	**2002**	**2003**
N supply (g pot^{-1})				
1.125	16.8 a	18.2 a	3.55 b	4.23 a
2.25	15.7 a	17.5 a	2.89 a	4.08 a
S supply (mg pot^{-1})				
75	15.6 a	17.3 a	2.89 a	3.60 a
225	16.2 a	17.7 ab	2.98 a	4.43 a
450	17.0 a	18.5 b	3.79 b	4.44 a
Nitrogen (N)	ns	ns	*	ns
Sulfur (S)	ns	*	*	ns
N x S	ns	ns	*	ns

Numbers with different characters in the same column indicate statistically different mean at the 5% levels (Tukey's test); * and ns: significant at 0.05 level and non significant

3.5.3 Correlation between N, S and inorganic and organic compounds in asparagus spears

The correlations coefficients between N and S and mineral and organic constituents are shown in table 3-43. The N content in asparagus spears significantly correlated with P, Zn, glutathione and cysteine content. But no significant correlation was found between N content and other nutrients or organic compounds (Table 3-43).

Significant correlation was found between S content in asparagus spears and SO_4-S and ascorbic acid content (Fig. 3-16). For the other nutrients and organic compounds no significant correlation was found (Table 3-43 and appendix Fig. 7-3).

Table 3-43: Correlation coefficient between N and S content and nutrient content in asparagus spears.

	N	P	K	Ca	Fe	Mn	Zn	Cu	SO_4-S	NO_3-N	Prot.	GSH	Cys	Ascorb
N		*** 0.68	ns 0.24	ns 0.20	ns 0.09	ns 0.21	** 0.42	ns 0.05	ns 0.03	ns 0.26		** 0.51	** 0.50	ns 0.02
S	ns 0.22	ns 0.14	ns 0.09	ns 0.18	ns 0.26	ns 0.27	ns 0.15	ns 0.24	** 0.72	ns 0.12	ns 0.22	ns 0.07	ns 0.13	* 0.36

Note: Ascorb: ascorbic acid; Prot.: Protein; GSH: glutathione; Cys: cysteine;
*,**, *** and ns: correlation is significant at the 0.05, 0.01,0.001 levels and none significant

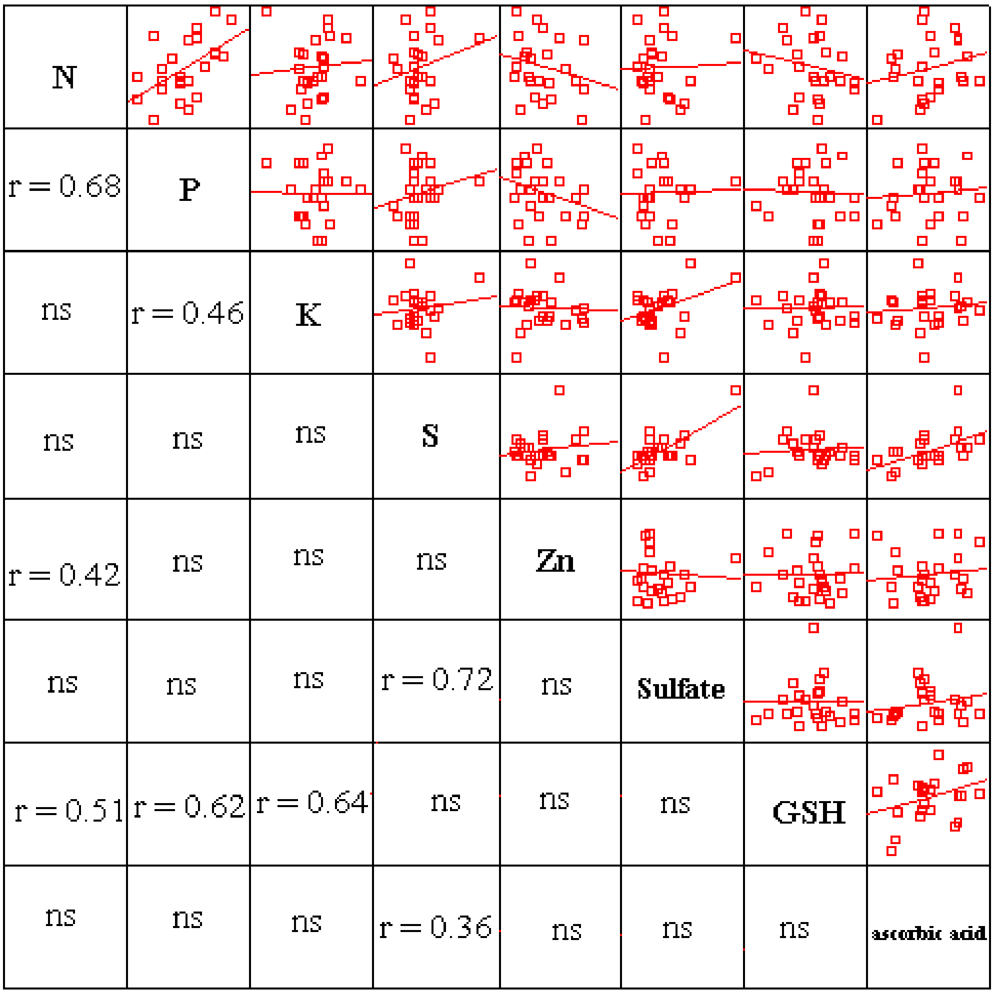

Fig. 3-16: Correlation matrix for plant nutrient concentration in spears of the cultivar *Hannibal* grown in a large pot experiment.

The results of large pot trial can be summarized as follows:

1- S supply significantly increased spear yield and number of spears per plant in the second harvest season.

2- N supply had no significant effect on spear yield, spear quality parameters as well as dry weight.

3- S supply significantly decreased NO_3-N content in spears of the cultivar *Hannibal*.

4- S fertilization significantly increased ascorbic acid content of the spears in both seasons, glutathione content in the second season and cysteine content in the first season.

5- N and S supply had no significant effect on the protein content in both harvest seasons.

6- N content in asparagus spears significantly correlated with P, Zn, cysteine and glutathione content.

7- S content in asparagus spears correlated positive and significant with SO_4-S and the ascorbic acid content.

4 DISCUSSION

The main objective of the presented work was to study the influence of genotype, cultivation region, nitrogen and sulfur supply on spear quality parameters and spear yield of asparagus. Asparagus is available in the market in green and white form. White asparagus is popular in Asia and Europe, while in the United States green asparagus is preferred (Cuppett et al., 1996). It is well suited not only for fresh use, but also for canning or deep freezing. Asparagus is an excellent source of vitamin A and it contains significant amounts of calcium, phosphorus, riboflavin and ascorbic acid (Marr, 1994). In addition to the primary metabolites protein, carbohydrates and lipids, asparagus contains a large number of biochemical constituents including flavonoids, amino acids derivatives, S-containing acids, vitamins and saponins (Chin et al., 2002). Recent studies indicate that some of these compounds possess health protective and pharmacological properties (Chin et al., 2002).

Concerns about human health in relation to the intake of food led to an increasing interest in the nutritional quality of food products. A high intake of vitamins, dietary fibers and some minerals and low intake of nitrate is supposed to protect against several life style diseases which occur in many industrialized countries (Sorenson, 1999). In this respect, S fertilizers could be applied to improve the protein and ascorbic acid content and decrease the NO_3 content.

4.1 Effect of cultivar and site on the composition and nutritional quality of asparagus

The average spear yield vary among others independence on cultivation region and cultivar. Seasonal variation in weather conditions like temperature and moisture affects asparagus yield and spears quality, too (Poll, 1995). Taste of asparagus differs independence on the cultivar and cultivation region. These experiments were carried out to weighting the genotypic factor against the environmental factors.

Data from crop performance trials revealed that there were significant genotypical differences for the S, Ca, NO_3-N, SO_4-S, Fe, Mn and Cu content in spears of asparagus cultivars grown at the experimental site in Burgwedel, Lower Saxony (Table 3-2) and only for the NO_3-N, SO_4-S content in spears of asparagus cultivars grown in Wiemersdorf, Schleswig-

Holstein (Table 3-1). The results indicate that the capability of different asparagus cultivars to use available soil nutrients is genetically controlled, while there are significant differences among asparagus cultivars for the most of nutrient concentrations and all of 15 cultivars grown under the same conditions. With view to consumer demands those cultivars should be preferable which accumulate less nitrate (Table 3-1 and 3-2). The nitrate content on production fields was in the range of leaf vegetables such as spinach and endive (Souci et al., 2000).
The fact that the total S concentrations were significantly lower in cultivars grown in Schleswig-Holstein could be related to a lower S supply and atmospheric S depositions in this area where severe S deficiency is a major nutrient disorder, and the fact that asparagus is usually grown on light sandy soils, which provide lower amounts of plant available S than heavier soils (Schnug and Haneklaus, 1998).

Nitrate is one of the most important non-protein N compounds, which particularly enriches in conductive plant tissue such as stems (Mills and Benton Jones, 1996). Makus (1995) reports in this context that green asparagus spears have a lower NO_3 content than white asparagus spears. Excess N fertilization increases the nitrate content and thus diminishes crop quality. Furthermore increased N losses to the environment are to be expected. Striking in this result is that the nitrate concentration was distinctly above the nutritional value of 1015 µg g^{-1} NO_3 which is supposed to be optimum for plant growth; maximum values were more than three times higher. In previous studies, it was found that, thickness and length of spears are related to the chemical composition of asparagus spears and, therefore, its nutritional value (Amaro et al., 1998). Significant differences in the mineral elements and other nutrients in the tip portion of the spear have been demonstrated and statistically significant differences between asparagus cultivars for all the elements analyzed were observed, too (Zurera and Moreno, 1990; Moreno et al., 1992; Amaro et al., 1998).

The effect of the cultivation region on the composition of asparagus spears was significant only for Ca, Mg and SO_4-S. In case of Ca and Mg the mean concentration was 380 µg g^{-1} and 80 µg g^{-1}, respectively higher in the area of Braunschweig than Erfurt (Table 3-11). Though, not only the soil pH of 6.9 was significantly higher in the region of Erfurt than in Braunschweig with pH 5.8, but also the plant available Mg content with 154 µg g^{-1} compared to 28 µg g^{-1} (Table 2-1), the concentration of Ca and Mg of the asparagus spear was

significantly lower. Whether this was related to a dilution effect because of a higher productivity in the Erfurt region remains open. In studies of Amaro et al. (1998) and Zurera et al. (2000) it was found that the chemical composition and mineral content of fresh asparagus was influenced by agronomic factors such as cropping area, cultivar and harvest time.
Besides different cultivation measures and soil properties, the genotype is responsible for the variation of the composition. The results in figure 4-1 reveal that the concentration of P, Ca, Mg, Fe, Zn and Cu and the protein content was distinctly lower than the corresponding nutritional values given by Souci et al. (2000).

In figure 4-1 the mean nutritional values for asparagus given by Souci et al. (2000) and Makus (1994) were set in relation to the measured parameters of the field survey and the experiments with different cultivars. The NO_3-N content of spears from production fields was on an average 113 µg g^{-1} higher than in the experiments with different cultivars. Under controlled experimental growth conditions only the Mg, Fe and Cu concentration was lower than the nutritional value of 0.27 % 105.2 and 23.5 µg g^{-1}, respectively (fig. 4-1). Comparative values from other investigations are rare, because cultivars differ between countries as well as growth conditions, sampling date and sample preparation.

The results from crop performance trials reveal that the differences between asparagus genotypes were not significant for the protein content in Wiemersdorf and Burgwedel and cysteine content in Burgwedel. Glutathione is an anti-oxidant and supposed to play a key role in the detoxification of xenobiotics and carcinogens in the human body (Richie, 1992). Furthermore, S containing secondary compounds are known to play a major role for sensory features (Holberg et al. 1999), but so far no relationship between total S content and such metabolites are throughoutly investigated.

Significant differences were found in this investigation in the glutathione content for different asparagus cultivars and genotypes from both experimental sites (Table 3-9 and fig. 3-7). The glutathione content in crop performance trials and field survey ranged from 24.5 to 40 mg 100 g^{-1} fresh spears. Asparagus is rich in glutathione with a mean value of 26 mg 100 g^{-1} fresh spears compared to other vegetables such as broccoli with 8 mg 100 g^{-1}, spinach with 5 mg 100 g^{-1}, tomato with 11 mg 100 g^{-1} or potato with 13 mg 100 g^{-1} (Pressman, 1997). In studies with other crops it was already shown that the S supply had a strong impact on the glutathione content (De Kok et al., 1981; Schnug et al., 1995). Furthermore the glutathione content of plants has been reported to be depended on season, day time and other exogenous factors such as sulfur nutrition and stress conditions (Rennenberg, 2001).

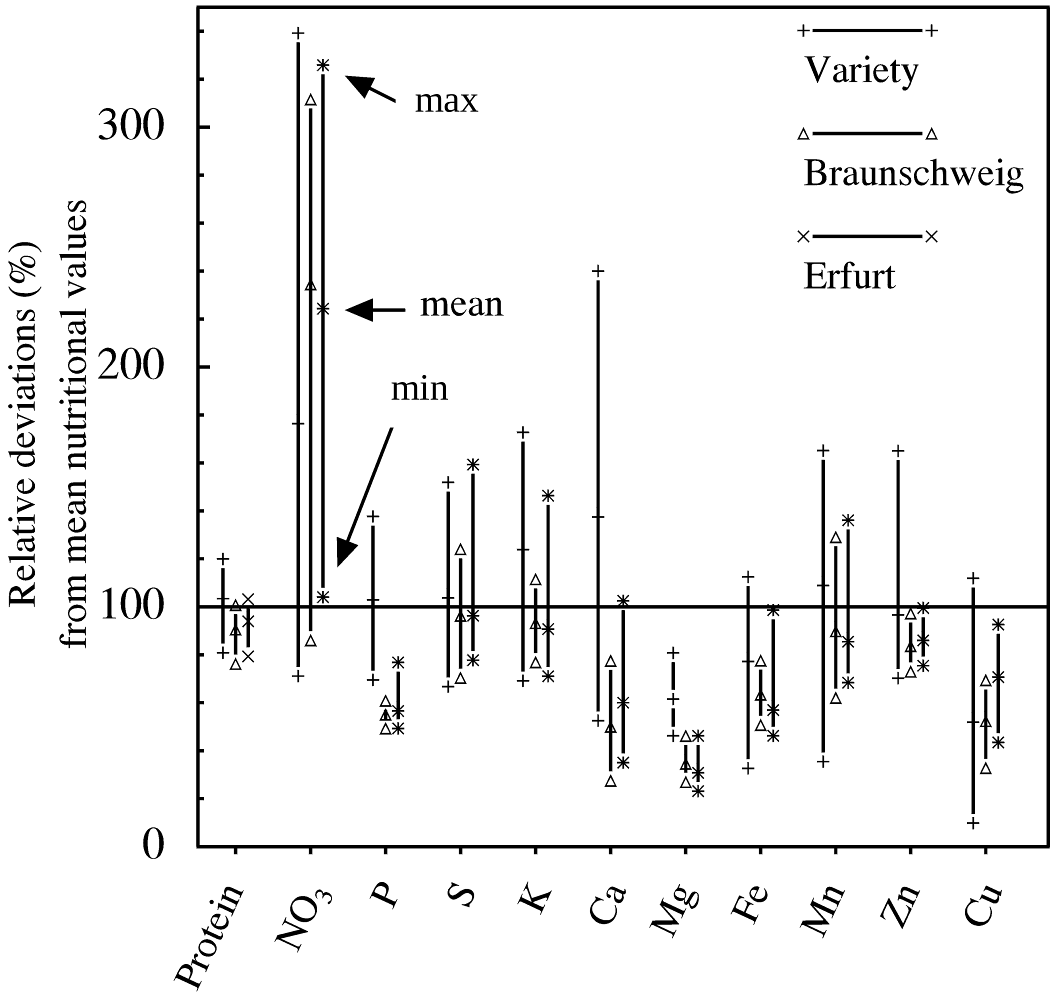

Fig. 4-1. Variation of quality parameters of white asparagus relatively to mean nutritional values (Souci et al., 2000; Makus, 1994) in dependence on region and cultivar (100% = 29.4% protein, 1015 µg g^{-1} NO_3, 0.69% P, 0.54% S, 3.11% K, 0.4% Ca, 0.27% Mg, 105.2 µg g^{-1} Fe, 15.8 µg g^{-1} Mn, 61.1 µg g^{-1} Zn and 23.5 µg g^{-1} Cu)

4.2 Influence of cultivar, N and S supply on asparagus transplants quality

Optimum plant growth of asparagus transplants is a prerequisite for an efficient production. The use of greenhouse grown transplants has become an important method in asparagus production (Benson et al., 1978). Under controlled condition the influence of fertilization can be seen best. Therefore, the effect of N and S supply on asparagus transplants growth and chemical composition was studied under greenhouse conditions in a pot trial with two asparagus cultivars (*Huchels Alpha* and *Hannibal*). The effect of N fertilization was significant on the all recorded vegetative parameters except for number of shoots of the cultivar *Huchels Alpha* and shoot dry weight of the cultivar *Hannibal* and increased all root growth parameters (Table 3-19 and 3-20). Sulfur fertilization increased vegetative and root growth in both cultivars (Table 3-19 and 3-20). Precheur and Maynard (1983) reported an increase in asparagus shoot and root growth with increasing N supply. In another study, Adler et al. (1984) found that the shoot dry weight increased with increasing N rate from 0 to 100 mg l^{-1} in the feeding solution. Waters et al. (1990) found that shoot dry weight was highly correlated with flashy root number and shoot vigor.

In the present study, the dry weight per plant was in similar range as found by Precheur and Maynard (1983) in a sand culture study with transplant of the cultivar *Rutgers Beacon*. Fisher et al. (1993 and 1996) found that shoot number and shoot length increased with each increase with the frequency N supplies. This suggests that growth of asparagus transplants would be further improved by increasing nutrient supply. For example, Fisher and Benson (1983) found that the concentration of 150 mg l^{-1} N in feeding solution was more efficient than 100 mg l^{-1} N for shoot and root growth of seedling transplants fed daily. In comparison the effect of S fertilization on the asparagus transplants is rare in the recent literature.

The cultivar *Hannibal* had a significantly higher shoot and root fresh and dry weight than the cultivar *Huchels Alpha*. So that it can be assumed that the cultivar *Hannibal* also would have produced a higher spear yield than *Huchels Alpha*. Stein (1987) and Fisher et al. (1993) found that there were differences among asparagus cultivars transplants in shoot and root growth. Baker (1989) suggested that differences in root morphology between cultivars in vegetable crops could account for differences in nutrient uptake.

The concentration of macro- and micro-nutrients in shoots and roots of asparagus transplants was not significantly affected by an increasing N supply (250 to 500 mg per plant) but the N content increased (Table 3-21 and 3-22). The positive correlation of tissue N content of asparagus transplant and N supply has already been reported by Fisher et al. (1993). The effect of S supply on the mineral content in shoots and roots of asparagus transplants was significant only for protein, N and S content (Table 3-23 and 3-24).

Although the cultivar *Hannibal* recorded higher shoot dry weight values than the cultivar *Huchels alpha*, the P and Mg contents in the shoots were lower in *Hannibal* than in *Huchels Alpha* (Table 3-23). One possible explanation is that the better shoot growth rate of *Hannibal* caused a dilution effect (Fisher et al. 1993). In the present study, the total N content on dry weight basis was less than those reported from other experiments (Fisher and Benson 1983; Spiers and Nichols, 1985 and Fisher et al. 1993) but higher than for P and K. These differences could be due to the differences in the level of nutrient supply or the age of the plant at the sampling date.

4.3 Influence of N and S supply on yield and chemical composition of asparagus

One of the most important factors affecting spear yield and quality is the cultivar, nitrogen and sulfur supply. Application of fertilizers may not only influence the yield and quality of vegetable crops but also the chemical composition of the marketable product. Therefore the application of fertilizers may be used to control and improve the nutritional quality of products used for human consumption (Sorenson, 1999).

In this study the response of four asparagus cultivars to sulfur fertilization was investigated. The results showed that S fertilization significantly increased S and SO_4-S content of spears of the cultivars *Huchels Alpha, Rekord* and *Ariane* grown in Lower Saxony and Schleswig-Holstein (Tables 3-14 , 3-15 and 3-17). In this respect, Eaton (1942) found in a study with tomato, sugar beet, alfalfa, cotton, milo and barley that S fertilization increased the SO_4 accumulation in plant tissue. Comparing the data from S application in spring with those from autumn application, it is obvious shown that spring application results a higher response of the nutrient content than autumn application. S fertilization may not affect the S content of the reproductive plant organs (grains and seeds) as much as the S content of the non-reproductive organs (stem and leaves) (Mengel, 1991). When the S demand for synthesis of organic compounds in the seeds is satisfied, excessive amount of absorbed S remain in the non-reproductive plant parts (Mengel, 1991). Hoppe et al. (1996) found that sulfur supply increased the total S content in leaves of garlic and onion plants. The same results were found for onion plants by Lancaster et al. (1999) and Randele et al. (1999). It is generally known that the nutrient level of crops is affected by the nutrient supply. In this study, it was found that S fertilization decreased NO_3-N content in spears of the cultivar *Schwetzinger Meisterschuss* grown at Gross Schwülper in the second season of experimentation. Nitrate tests of vegetables are necessitated by the deleterious effect of nitrate on the human organism. The problem is even more important in baby food where it must not surpass 50 ppm (Cserni and Prohaszka, 1987). The nitrate content of vegetables can vary considerably depending on species and cultivars (Claus, 1983). Besides environmental factors it is mostly affected by the nutrient supply. Crop rotation can also decrease the high NO_3 uptake of plants (Cserni and Prohaszka, 1987).

Interaction between N and S have an important side effect on the environmental impact of agricultural production, because the utilization efficiency of N by plant is reduced under condition of S deficiency and this in return increases undesired losses of N from agricultural production fields to the environment (Schnug and Haneklaus, 2000). Because there are nutrient losses by leaching in fertilization trials under field conditions, the influence of N and S supply on the yield and chemical composition of asparagus spears was investigated in a large pot trial. The results from this experiment reveal that the N supply had a significant effect on the Mn and Cu content of asparagus spears from the second season (Table 3-32 and 3-33). The NO_3-N and Mn content was significantly lower in the second season than in the first one and this could be due to a dilution effect since the yield in the second season was two times higher than in the first season. S supply did not effect the chemical composition of the asparagus spears with the exception that it lowered the NO_3-N content in both seasons.

Data presented in table 4-1 show the mean content of mineral nutrients in asparagus spears grown in the large pot trial, crop performance trials, field survey and field experiments with S fertilization in comparison with the mean nutritional value reported by Souci et al. (2000). The data show that the N, S, NO_3-N and SO_4-S content was considerably lower and the Mn content higher in asparagus spears grown in large pots. The P content was lower in asparagus spears in field survey but NO_3-N was two times higher than corresponding value reported by Souci et al. (2000).

Table 4-1: Mean nutrient content of spears grown in large pot, crop performance trials, field survey and field trials as well as mean nutrient value.

Nutrient	Unit	Large pot trial	Crop performance trials	Field survey	Sulfur fertilization trials	Mean nutritional value (Souci et al., 2000)
N	mg g^{-1}	31.5	48.6	43.3	41.4	47.6
P	mg g^{-1}	4.3	7.0	3.9	5.1	6.9
K	mg g^{-1}	25.1	38.5	28.6	33.0	31.1
S	mg g^{-1}	3.2	5.6	5.2	5.0	5.4
Ca	mg g^{-1}	2.0	5.6	2.3	2.4	4.0
Mg	mg g^{-1}	1.1	1.6	0.9	1.4	0.7
Fe	µg g^{-1}	50.6	83.3	63.3	72.1	105
Zn	µg g^{-1}	53.7	58.2	51.8	51.9	61.1
Mn	µg g^{-1}	38.8	17.7	13.8	15.4	15.8
Cu	µg g^{-1}	27.8	11.7	14.4	11.8	23.5
SO_4-S	µg g^{-1}	81.3	179	101	89.5	--
NO_3-N	µg g^{-1}	210	371	526	350	229

The results of field trials with S fertilization indicate that S fertilization increased the total protein content in spears of the cultivars *Ariane*, *Huchels Alpha*, *Rekord* and *Schwetzinger Meisterschuss* but the difference between the control and fertilized spears was statistically not significant (fig. 3-9, 3-10, 3-11 and 3-12). In this context it has to be considered that the final effect of S fertilization in dependent on the initial S status of the crop. S-deficient crops are supposed to react stronger than none S-deficient crops.

The glutathione content of all previous cultivars was increased by increasing S fertilization but the differences were statistically not significant (Fig. 3-13). In studies with other crops it was shown that the S supply had a strong impact on the glutathione content (De Kok et al., 1981; Schnug et al., 1995). In the large pot trial, The correlation between total S content of asparagus spears and glutathione content was not significant (Fig. 3-16). The reasons for this could be that in this experiment the S supply was scarce even in the highest fertilization level. Under such circumstances the plant would be able to synthesize excess glutathione or show a positive response to S fertilization for the glutathione content. On the other hand, Hoppe et al. (1996) and Bloem, et al. (2002) found a significant relationship between the total S content and iso-Alliin concentration in the leaf tissue of garlic and onion. S enhanced crop quality in terms of crude protein and vitamin. This could be attributed to the role of S as a constituent of some amino acids which are needed in enzyme systems involving N metabolism (Kleinhenz, 1999).

In the large pot trial with the cultivar *Hannibal*, increasing N supply had no significant effect on the protein, glutathione and ascorbic acid content but had a significant effect on cysteine content in spears of the cultivar *Hannibal* (Table 3-41 and 3-42). Makus (1995) found that the total protein content of the cultivar *Jersey Giant* grown in silt loam soil was not affected by N application. In another study, Omran (1998) found that a treatment with a 100:50:50 fertilizers N, P, K units yielded the highest protein content of the cultivar *UC157* compared with other four combinations of N, P and K. In this respect, Mineroamador et al. (1992) reported that the total protein content of the cultivars *Jersey Continental* and *Lucullus* was 23.1% and 24.4 %, respectively. Makus and Konzalez (1991) found that white asparagus spears had significantly lower protein than the green asparagus spears.
Lai et al. (1973) found that the ascorbic acid content ranged from 20 to 38 mg 100 g^{-1} fresh white and green asparagus spears. Ascorbic acid content in the spear tip was higher than in the spear base (Makus, 1994). Omran (1998) found no significant effect of different treatments with N , P and K on the ascorbic acid content.

Increasing S supply from 75 mg to 450 mg per pot significantly increased the ascorbic acid content in asparagus spears in both harvest seasons and the glutathione content in the second season and cysteine content in the first season in the large pot trial (Table 3-41 and 3-42), but had no significant effect on the protein content in both seasons. Ojo and Oputa (1999) found, on another plant, that S supply increased ascorbic acid content and explained this by the fact that S enhances the photosynthetic carbon fixation.

Data presented in table 4-2 show that the protein content of the asparagus spears from crop performance trials was distinctly higher than these in the large pot trial. The glutathione and cysteine content was higher in the field trials with S fertilization than in the other trials.

Table 4-2: Mean protein, cysteine and glutathione content in large pot trial, crop performance trials, field survey and field trails in comparison with mean nutritional value for asparagus by Souci et al. (2000) and Pressman (1997).

Constituent	Unit	Large pot trial	Crop performance trials	Field survey	Sulfur fertilization trials	Mean nutritional value
Protein	%	18.7	30.6	27.1	26.0	29.4
Glutathione	µmol g^{-1}	17.0	19.4	20.0	27.0	13.0
Cysteine	µmol g^{-1}	3.7	2.5	4.7	5.8	--

Since nitrogen and sulfur are constituents of protein and involved in chlorophyll formation, their supply is closely related to the biosynthesis of organic compounds in plants. Nitrogen is presented in all amino acids, protein and coenzymes and S in some of them. When the S supply is insufficient, synthesis of S-containing organic compounds is inhibited (Kleinhenz, 1999). Because the S-containing amino acids cysteine and methionine are essential for building proteins, S deficiency results in general in an inhibition of the protein synthesis (Von Uexküll, 1986). Under condition of S deficiency, the synthesis of S-containing amino acids and protein is depressed. Therefore, the application of S is frequently associated with increases of amino acids in crops (Baksh et al. 1986; Hoching et al., 1996). Among the higher plants, particularly Liliaceae and Brassica crops are highly S demanding. This can be explained by the fact that they use sulfur for the synthesis of specific S-containing metabolites such as glucosinolates and allins (Luckner, 1977).

The flavor of fresh asparagus is due to S-containing compounds. Tressel et al. (1977) found that the flavor of fresh asparagus is due to the S-containing asparagusic acid and its methyl and ethyl esters. The same author found that the concentration of the esters amounts to 7 ppm, whereas the free asparagusic acid amounts to approximately 3 ppm. Because the flavor of asparagus is due to S-containing compounds it can be expected that increasing S supply will increase asparagus flavor. Kosjan et al. (1997) determined close a correlation between the amount of S fertilizer and the accumulation of S-containing organic substances in garlic bulb. An increasing S rate from 0 to 100 kg ha^{-1} led to an increase of organic sulfides and sulfoxides in garlic bulbs independent of the cultivars grown (Kosjan et al., 1997). Many of the substances which are responsible for a particular quality aspects of plant products are sulfur containing compounds. Therefore it is no surprise that sulfur is the plant nutrient which has perhaps the strongest impact on plant quality (Schnug, 1997). Most of the variability in quality parameters, as a result of S metabolism, is caused by environmental rather than genetic factors. This explains, for instance, why the same cultivars of the same vegetable can have a different taste if they are grown at different sites (Schnug, 1997).

Since fern vigor is correlated with high yields (Ellison et al., 1960) this parameter was investigated in relation to the N and S supply on the number of main shoots per plant and plant height. The production of vigorous asparagus spears is generally dependent on the reserve in storage roots (Lin, 1984). The results from the large pot trial show that increasing N supply had no significant effect on the number of main shoots per plant and the plant height of one or two years old asparagus plants as well as the spear yield in both harvest seasons (Table 3-27 and 3-28). In commercial production, N is the element most considered to be deficient. In the physiology of the plant, it is a very mobile element, interfering with many components (Jones, 1966). Makus (1995) found that a supplemental N fertilization had no effect on the number of green and white asparagus spear and yield per hectare. Warman (1991) found that N fertilization did not significantly influence the yield and the yield increased with increasing crown age. The same author found that the response of asparagus to fertilizer treatments varied from site to the other. Roth and Gardner (1989) reported that the amount of N required varied each growing season because of the climatic conditions. Harvested yield varied each growing season because the age of the crown was increased. On the other hand, Brown and Carolus (1965) found only a weak correlation between N, P, and K application and asparagus yield. Sanders (1999) reported that there is statistically no significant difference between 50, 100 and 150 kg N ha^{-1}. But Sanders and Bandele (1984) found also that yield increased during the first four years with increasing N rate up to 168 kg ha^{-1} and K rate up to 93 kg ha^{-1}. Brasher (1958) reported that increasing N, K and B rates increased yield on sandy loam soils however, P only increased fern P content but not the yield. Krarup (1990) reported that P was the most important element as regards yield but a high rate of fertilization was unnecessary. In contrary, Brown et al.(1961) and Espejo et al., (1996) reported that yield to be unaffected by increasing P fertilization. Phosphate fertilization had no influence on the properties of the spear obtained but gives rise to increase spear diameter. High N rate and high organic matter level decreased fibrous root development. Increasing N fertilizer level resulted in a decrease in total crown fructose concentration and an increase in fern growth (Pitman et al., 1991). Growth retardation subsequently may limit the yield potential, especially in the areas with short growing season (Adler et al., 1984). Therefore, the development of vigorous root system should be encouraged during transplant production by balance fertility practices (Adler et al., 1984). But also here it has to be criticized in general that any report on the effect of a treatment with nutrients has to consider the initial supply status.

Generally, nitrogen recommendation for asparagus plants varies independent on the cultivation area, soil fertility, yield potential of the grown cultivar and the age of plants (Krug and Kailuweit, 1999). Carolus (1962) suggested that N fertilizer rate can be reduced since a 500 kg ha^{-1} yield removed only 21 kg N. Thus adapting N fertilization as closely as possible to the N demand of asparagus is an important question of sustainability. Hartmann et al. (1983) found that N fertilization more than 100 kg ha^{-1} had no significant effect on asparagus yield. The same authors compared application of 100 kg with 250 kg and 400 kg ha^{-1} N. It was found that the yield of 250 kg and 400 kg ha^{-1} N was 97.4% and 98.6% from that yield of 100 kg ha^{-1} N. Hartmann, (1989) reported that increasing N fertilization had no significant effect on the fern N content because with increasing N fertilization N content of under ground part of asparagus increased. It was found that the ratio between N content in the shoot and root (root and crown) was 1 : 0.62 under sufficient N application but these ratio was 1 : 2.12 under high N application (Hartmann, 1989).

In this work the effect of S supply on asparagus yield and number of spears per plant was significant in the second harvest season and there was no significant differences between 225 mg and 450 mg S per pot. Fig. (4-2) shows that spears yield was significantly higher in the second harvest season than the first season. This is due to little storage of starch to support high spear yield in the small young crowns (Mullin and Swingle, 1979; Poll, 1995). The fact that S enhances yield and quality could be due to the fact that S enhances photosynthetic carbon fixation (Ojo and Oputa, 1999).

Application of fertilizers to the asparagus plants is in spring or in Autumn. Hartmann (1989) reported that there was no significant difference between application of fertilizers before the harvesting time (in April) and after the harvesting time (in June). The same author reported that N application in April produced 100 % yield and in June produced 99.2 %. (Hartmann, 1989).

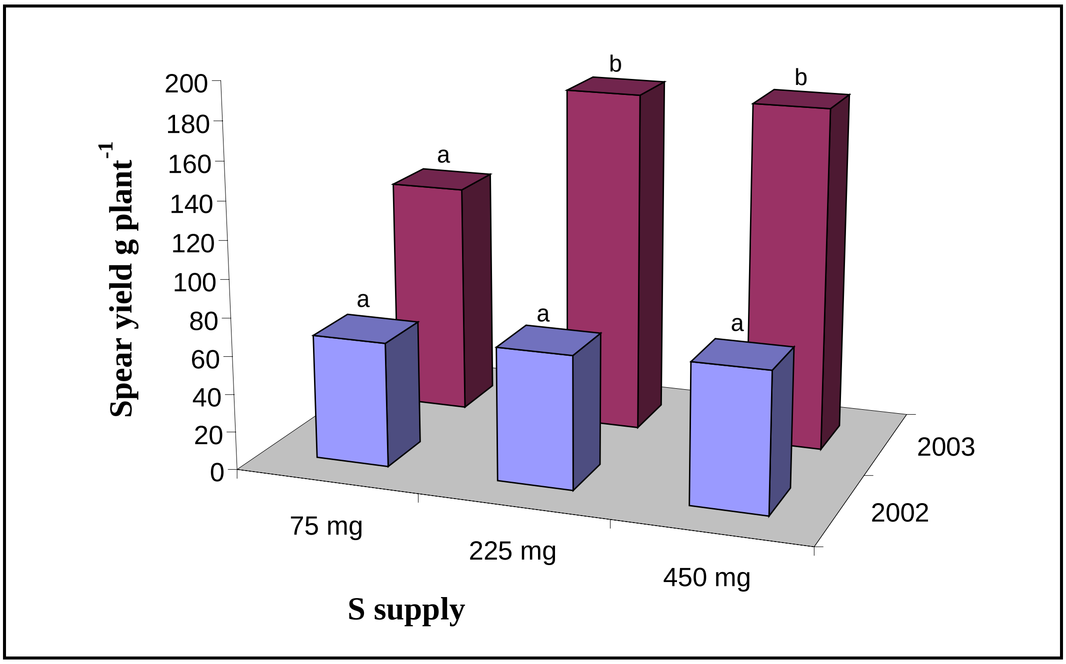

Fig 4-2: Asparagus spears yield of the cultivar *Hannibal* as affected by S supply in years 2002 and 2003 in a large pot experiment.

N fertilization becomes a matter of concern because of costs and possible contamination of water system when overdose was applied (Krarup et al., 2002). Since N fertilization had no significant effect on asparagus spears yield in the large pot trial and increases NO_3 content it can be recommended that 50 to 100 kg N ha^{-1} is sufficient for asparagus plants independence on cultivation area, soil fertility, yield potential of the grown cultivar and the age of plants. Because S fertilization increased yield and spears quality it can be recommended that S supply is very important for asparagus cultivation. Since excess N fertilization increased NO_3 content and thus diminishes spear quality and increased N losses to the environment it can be recommended decreasing in N supply to the sufficient amount which produce good yield with high quality.

Concerns about human health in relation to the intake of foods have led to an increasing interest in the nutritional quality of food products. Since the mineral nutrient levels in asparagus spears are influenced by the length of the spear, reducing the inedible fibrous portion (butt end) would reduce transportation costs and provide consumers with a nutritionally better products with respect to essential minerals (Makus, 1994).

5 SUMMARY

Asparagus (*Asparagus officinalis* L.) is a vegetable of high nutritional and economic relevance because of its high dietary value and its availability at a time of the first half of year when there is a shortage of fresh vegetables on the market. Asparagus is one of the most important vegetable crops in Germany. It covers a production area of about 15,000 hectares with annual spears production approaching 55,000 tons with a total value of more than 150 million Euro. Asparagus is also a medicinal plant which has a diuretic effect and was identified as being beneficial for humans with heart disease. Asparagus spears are rich in glutathione content (15 - 30 µmol g^{-1} dw), which is an anti-oxidant and supposed to play a key role in the detoxification of xenobiotics and carcinogens in the human body. Spears are also rich in ascorbic acid content with 19 - 38 mg 100 g^{-1} (fw). The main objective of the present research work was to investigate the influence of genotype, cultivation region and sulfur and nitrogen supply on quality parameters of white asparagus spears.

Crop performance trials were carried out in 2001 with 15 cultivars and new genotypes at Burgwedel (52° 37.4' N; 9° 50.2' E), Lower Saxony, and with 5 cultivars at an experimental site in Wiemersdorf (53° 52.7' N; 10° 20.6' E), Schleswig-Holstein, in order to determine the effect of genotype on quality parameters of spears. In 2000 an extended field survey was conducted in the regions of Braunschweig (52°19.0`N; 10°29.1`E) and Erfurt (51°01.4`N; 11°02`E) in order to study the influence of the cultivation region on spear quality parameters.

The main results of the investigations can be summarized as follows:

1. Asparagus cultivars and genotypes grown in Burgwedel showed significant differences in the glutathione, S, Ca, NO_3-N, SO_4-S, Mn, Fe and Cu content. The cultivar *Eposs* had the highest glutathione content with 20.5 µmol g^{-1}.
2. Significant differences were found in the SO_4-S, NO_3-N and glutathione content for different asparagus cultivars grown in Wiemersdorf. The cultivars *Boonlim* and *Huchels Alpha* had the highest glutathione content with 25.2 and 25.3 µmol g^{-1}.
3. The cultivar *Ramos* and the genotype *96012* had the lowest NO_3-N content with 251.5 and 294.6 µg g^{-1} (dw).
4. Asparagus cultivars and genotypes showed no significant differences in the protein content among both sites.
5. Asparagus cultivars grown in Lower Saxony had higher S and SO_4-S content than those grown in Schleswig-Holstein.

6. Regional differences in the composition of asparagus spears were significant between the Braunschweig and Erfurt region for Ca, Mg and SO_4-S.
7. There were significant relationships between the content of S, SO_4-S, Mn, Fe and Cu in asparagus spears and that in fern.

In field trials at different locations in Germany, the response of four asparagus cultivars to sulfur supply was investigated. At three locations in Braunschweig (Lower Saxony) in 1999 and 2000 and one in Alt-Mölln (Schleswig-Holstein) in 2001, 100 kg ha^{-1} S as potassium sulfate in Lower Saxony and as elemental sulfur in Schleswig-Holstein was applied after the harvest season in Lower Saxony and before the harvest season in Schleswig-Holstein.

The main results of the field experiments can be summarized as follows:

1. S fertilization had a significant positive influence on the S and SO_4-S content of spears of the cultivars *Ariane*, *Huchels Alpha* and *Rekord* but the differences in the S and SO_4-S content was not significant for the cultivar *Schwetziner Meisterschuss*.
2. S fertilization significantly decreased NO_3-N content of the cultivar *Schwetzinger Meisterschuss* grown in Gross Schwülper in the second year.
3. The glutathione content of all cultivars increased by S fertilization but differences proved to be statistically not significant.
4. The protein content of all cultivars and the cysteine content of the cultivars *Ariane* and *Huchels Alpha* were not significantly affected by S fertilization. The cysteine content of the cultivars *Rekord* and *Schwetzinger Meisterschuss* significantly increased by S fertilization.

Under greenhouse conditions, Mitscherlich pot and large pot experiments were carried out in order to study the influence of N and S supply on growth, yield and chemical composition of asparagus. In “Mitscherlich” pots seedlings of two asparagus cultivars (*Huchels Alpha* and *Hannibal*) were used. N was applied at two levels with 250 mg and 500 mg N per pot and S at three levels with 1 mg, 5 mg and 25 mg S per pot. In a large pot experiment, one year old crowns of the cultivar *Hannibal* were cultivated, one crown per pot, and treated with 1.125 g or 2.25 g N and 75 mg, 250 mg or 450 mg S per pot.

The main results of these investigations can be summarized as follows:

1. The cultivar *Hannibal* produced a higher number of shoots and fresh and dry weight than the cultivar *Huchels Alpha*.
2. N supply significantly increased plant height and fresh and dry weight of both cultivars, but had no effect on the chemical composition of shoots of both cultivars, except for N and NO_3-N content.
3. S supply increased vegetative growth of both cultivars. S fertilization increased protein and SO_4-S in shoots of the cultivar *Huchels Alpha*.
4. S supply significantly increased spear yield and number of spears per plant in the second harvest season but N supply had no significant effect on spear yield, spear quality parameters and ascorbic acid content.
5. S supply significantly increased glutathione content only in the second season and ascorbic acid content of spears in both seasons. But decreased NO_3-N content.
6. N content in asparagus spears significantly correlated with P, Zn, cysteine and glutathione content. S content in asparagus spears correlated positive and significant with SO_4-S and ascorbic acid content.

Zusammenfassung

Genetische und ernährungsbedingte Einflüsse auf die Qualität von Spargel (*Asparagus officinalis* L.)

Spargel (*Asparagus officinalis* L.) ist ein Gemüse der hohen Ernährungs- und ökonomischen Bedeutung, da es einen hohen diätetischen Wert hat und außerdem zu einer Jahreszeit zur Verfügung steht, zu welcher ansonsten wenig Frischgemüse auf dem Markt ist. In Deutschland wird auf rund 15.000 Hektar Ertragsfläche Spargel angebaut. Die gesamte Erntemenge beträgt jährlich etwa 55.000 Tonnen mit einem Gesamtwert von mehr als 150 Millionen Euro. Zugleich ist es eine Medizinalpflanze mit diuretischer Wirkung, auch wurde ein positiver Effekt bei Menschen mit Herzkrankheiten festgestellt. Die Sortenwahl entscheidet bei Spargel stärker als bei andern Gemüsearten über den wirtschaften Erfolg des Anbaus. Hauptanliegen dieser Studie war es, den Einfluß von Genotyp, Anbauregion sowie Schwefel- und Stickstoffzufuhr auf Qualitätsparameter des Spargels zu untersuchen.

Die Untersuchungen fanden an verschiedenen Standorten in Deutschland statt. Sortenleistungstests wurden in 2001 mit 5 Sorten am Versuchsstandort Wiemersdorf (53° 52.7' N; 10° 20.6' E), Schleswig-Holstein, und mit 15 Sorten und Neuzuchtstämmen am Versuchsstandort Burgwedel (52° 37.4' N; 9° 50.2' E), Niedersachsen, durchgeführt, um den Einfluss des Genotypus auf Qualitätsparameter der Stangen zu ermitteln. In 2000 wurde eine umfangreiche Felderhebung in den Regionen Braunschweig (52°19.0`N; 10°29.1`E) und Erfurt (51°01.4`N; 11°02`E) durchgeführt, um den Einfluss der Anbauregion auf Qualitätsparameter des Spargels zu untersuchen.

Die Hauptergebnisse dieser Untersuchungen können wie folgt zusammengefasst werden:

1. Bei SO_4-S, NO_3-N und Glutathion-Gehalt wurden signifikante Unterschiede zwischen den verschiedenen in Wiemersdorf angebauten Spargel-Sorten gefunden.
2. Die in Burgwedel angebauten Spargel-Sorten und Genotypen zeigten signifikante Unterschiede hinsichtlich der Gehalte an S, Ca, NO_3-N, SO_4-S, Mn, Fe, Cu und Glutathion. Die Sorte Eposs hatte mit 20,5 µmol g-1 den Hochesten Glutathion-Gehalt.
3. Die Sorte Ramos und der Neuzuchtstamm 96012 hatten mit 251,5 und 294,6 µg g^{-1} TM die niedrigsten NO_3-N-Gehalte.

4. Spargel-Sorten und Neuzuchtstämmen beider Standorte zeigten keine signifikanten Unterschiede hinsichtlich der Proteingehalte.
5. Die in Niedersachsen angebauten Spargel-Sorten hatten höhere S- und SO_4-S-Gehalte als die in Schleswig-Holstein angebauten Sorten.
6. Hinsichtlich Ca, Mg und SO_4-S gab es regionale Unterschiede in der Zusammensetzung der Spargelstangen zwischen der Braunschweiger und der Erfurter Region.
7. Zwischen den Gehalten von S, SO_4-S, Mn, Fe und Cu in den Spargelstangen und Spargelkraut waren signifikante Zusammenhänge festzustellen.

An drei Braunschweiger Standorten (Niedersachsen) sowie einem Standort in Alt-Mölln (Schleswig-Holstein) wurde der Einfluss von Schwefel-Düngung auf Stangen-Qualitätsparameter von vier Spargelsorten in Feldexperimenten untersucht. 100 kg ha^{-1} S wurden in Niedersachsen als Kaliumsulfat nach der Erntesaison und in Schleswig-Holstein als Elementarschwefel im Frühjahr vor der Erntesaison aufgebracht.

Die wichtigsten Ergebnisse der Feldexperimente lassen sich wie folgt zusammenfassen:

1. S-Düngung hatte bei den Sorten Ariane, Huchels Alpha und Rekord einen signifikanten Einfluss auf die S und SO_4-S-Gehalte der Stangen, dies galt jedoch nicht für die Sorte Schwetzinger Meisterschuss.
2. Der Proteingehalt wurde bei keiner Sorte durch S-Düngung signifikant beeinflusst, bei den Sorten Ariane und Huchels Alpha war auch kein signifikant Einfluss auf den Cystein-Gehalt erkennbar.
3. Der Glutathion-Gehalt aller Sorten wurden durch S-Düngung gesteigert.
4. Die Frühjahrsdüngung mit S hatte eine stärkere Reaktion der S-Gehalte in den Stangen zur Folge als die Herbstdüngung.

Im Gewächshaus wurden Topf- und Großgefäßversuche durchgeführt, um den Einfluss der N- und S-Zufuhr auf Wachstum, Ertrag und chemische Zusammensetzung des Spargels zu untersuchen. Samen von zwei Spargel-Sorten (Huchels Alpha und Hannibal) wurden in Mitscherlich Gefäße gesetzt. N wurde in zwei Stufen mit 250 und 500 mg N je Gefäß und S in drei Stufen mit 1, 5 und 25 mg je Gefäß zugegeben. Im Großgefäßversuch wurden einjährige Kronen der Sorte Hannibal kultiviert (1 Krone je Gefäß) und mit 1,125 bzw. 2,25 g N sowie 75, 250 bzw. 450 g S je Gefäß zugegeben.

Folgende Hauptergebnisse wurden erzielt:

1. Die Sorte Hannibal brachte eine größere Anzahl von Schösslingen sowie höhere Frisch- und Trockenmassen hervor als die Sorte Huchels Alpha.
2. Mit der N-Zufuhr wurden Pflanzenhöhe sowie Frisch- und Trockenmasse beider Sorten signifikant erhöht, jedoch war, mit Ausnahme der N- und NO_3-N-Gehalte, keine Wirkung auf die chemische Zusammensetzung der Kraut festzustellen.
3. Durch die S-Zufuhr wurde das vegetative Wachstum beider Sorten signifikant erhöht. Die S-Düngung führte zu höheren Protein- und SO_4-S-Gehalten der Kraut von Huchels Alpha.
4. Mit der S-Zufuhr stiegen der Stangenertrag sowie die Anzahl von Stangen je Pflanze in der zweiten Erntesaison an.
5. Die N-Zufuhr hatte keinen signifikanten Einfluss auf Stangenertrag, Stangen-Qualitätsparameter und Ascorbinsäure-Gehalt.
6. Die S-Zufuhr führte zu einer signifikanten Steigerung der Ascorbinsäure-Gehalte der Spargelstangen in beiden Erntsaison und Glutathion-Gehalt in der zweiten Erntesaison.
7. In keiner Erntesaison war ein signifikanter Einfluss der N- und S-Zufuhr auf den Protein-Gehalt feststellbar.
8. Zwischen dem N-Gehalt der Spargelstangen und ihren P-, Zn-, Cystein-und Glutathion-Gehalten bestanden signifikante Korrelationen. Der S-Gehalt der Spargelstangen korrelierte positiv und signifikant mit den SO_4-S- und Ascorbinsäure-Gehalten.

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7 Appendix

Table 7-1: Chemical analysis of soil samples taken from Braunschweig and Erfurt (field survey in 2000).

Site	pH	P µg g^{-1}	K µg g^{-1}	S_{min} Kg ha^{-1}	N_{min} Kg ha^{-1}	Mg mg kg^{-1}	Total C (%)	Total N (%)	Total S (%)
Braunschweig	6.4	93	131	12	16	44	0.3	0.04	0.01
Braunschweig	6.4	51	60	8	12	17	0.3	0.05	0.01
Braunschweig	6.2	47	60	31	39	15	0.2	0.04	0.01
Braunschweig	4.7	105	80	8	12	15	0.2	0.02	0.01
Braunschweig	6.0	149	130	8	24	29	0.4	0.04	0.01
Braunschweig	6.6	214	140	16	27	30	0.8	0.07	0.01
Braunschweig	4.9	120	80	20	20	22	0.4	0.04	0.01
Braunschweig	7.4	342	140	31	43	49	0.9	0.08	0.01
Braunschweig	6.5	76	110	8	16	24	0.5	0.05	0.01
Braunschweig	7.2	151	140	2	16	23	0.4	0.03	0.01
Braunschweig	5.7	4	300	27	27	26	0.6	0.05	0.01
Braunschweig	6.6	89	110	133	90	48	0.3	0.03	0.01
Braunschweig	6.9	202	140	43	51	46	0.6	0.06	0.01
Braunschweig	5.6	98	230	144	172	57	0.5	0.06	0.01
Braunschweig	5.3	76	180	273	238	37	0.3	0.04	0.01
Braunschweig	5.0	100	100	51	63	17	0.4	0.04	0.01
Braunschweig	6.4	115	160	20	109	23	0.6	0.06	0.01
Braunschweig	5.8	147	120	58	109	18	0.4	0.05	0.01
Braunschweig	4.5	140	130	160	90	36	0.5	0.05	0.01
Braunschweig	5.5	122	60	16	28	30	0.2	0.02	0.01
Braunschweig	4.9	91	60	23	28	7	1.0	0.08	0.01
Braunschweig	4.5	53	50	8	16	8	0.8	0.05	0.01
Braunschweig	5.7	85	100	86	101	30	0.9	0.07	0.01
Braunschweig	4.5	82	140	35	59	13	0.5	0.05	0.01
Erfurt	6.5	33	50	20	106	191	2.1	0.22	0.03
Erfurt	7.1	27	40	23	121	187	2.3	0.24	0.03
Erfurt	7.4	25	70	31	199	191	2.3	0.23	0.03
Erfurt	7.3	24	30	20	109	206	2.0	0.22	0.03
Erfurt	7.2	31	30	12	86	142	1.9	0.2	0.03
Erfurt	7.3	29	90	23	102	190	2.3	0.22	0.03
Erfurt	7.4	25	60	23	82	145	2.2	0.2	0.03
Erfurt	7.1	67	120	31	86	194	2.1	0.22	0.03
Erfurt	7.3	53	90	31	94	199	2.1	0.24	0.03
Erfurt	6.3	44	100	20	78	242	1.9	0.20	0.03
Erfurt	6.5	32	50	16	66	227	1.8	0.21	0.03
Erfurt	7.4	36	60	16	86	121	2.5	0.18	0.02
Erfurt	7.5	31	50	23	113	117	2.7	0.18	0.03
Erfurt	6.8	45	80	20	86	207	2.0	0.23	0.03

Table 7-1: continued

Site	pH	P (µg g^{-1})	K (µg g^{-1})	S_{min} Kg ha^{-1}	N_{min} Kg ha^{-1}	Mg (mg kg^{-1})	C-org (%)	Total N (%)	Total S (%)
Erfurt	7.0	30	70	27	98	211	2.1	0.24	0.03
Erfurt	6.4	22	60	16	70	194	2.0	0.21	0.03
Erfurt	7.0	68	90	20	20	81	0.9	0.07	0.01
Erfurt	6.7	26	60	39	36	78	1.5	0.13	0.02
Erfurt	5.6	44	110	12	16	15	0.7	0.07	0.01
Erfurt	6.6	34	30	31	39	61	0.7	0.07	0.01
Erfurt	5.6	35	60	23	47	43	0.8	0.08	0.01

Table 7-2: Macro-nutrient content of spear samples grown in Braunschweig (field survey in 2000).

cultivar	N	P	K	S	Ca	Mg
	….. mg g^{-1}..					
Rekord	42.6	4.15	34.74	6.17	2.60	0.96
Eposs	47.4	4.01	31.25	6.65	2.59	1.18
Bonlim	46.1	3.73	29.00	5.50	2.18	1.02
Vulkan	46.1	3.84	30.69	6.24	2.28	1.05
Mars	37.4	3.37	23.87	4.39	1.66	0.80
Rekord	42.2	3.79	28.87	4.77	1.79	0.90
Bonlim	40.3	3.77	30.27	5.80	2.57	0.89
H. leistungsauslese	45.2	3.76	27.17	4.36	1.33	0.89
Rekord	35.8	3.49	25.18	3.79	1.13	0.94
++	46.9	3.90	27.99	5.11	2.33	0.95
Huchels Alpha	41.1	3.90	29.65	4.85	1.84	0.92
Rekord	44.1	4.00	29.98	5.36	1.88	0.98
Horlim	40.5	4.17	33.20	6.36	3.11	0.98
Gijnlim	40.9	3.57	25.84	4.72	2.58	0.88
Gijnlim	42.7	3.82	28.37	5.06	2.14	0.95
++	41.6	3.92	31.49	5.38	1.84	0.96
S. Meisterschuss	46.0	3.74	30.05	5.07	1.75	0.95
S. Meisterschuss	44.5	3.61	27.37	4.79	1.63	0.74
S. Meisterschuss	39.5	3.57	28.64	5.26	1.82	0.81
Huchels Alpha	39.1	3.49	25.02	4.22	1.60	0.66
Huchels Alpha	42.7	3.83	28.47	4.82	1.56	0.88
Huchels Alpha	42.3	3.74	30.09	5.94	2.52	1.01
Huchels Alpha	43.7	3.98	33.45	6.67	2.33	1.09
++	415	3.45	25.89	4.22	1.35	0.79

Note: ++ unknown

Table 7-3: NO_3-N SO_4-S and micro-nutrient content of spear samples grown in Braunschweig (field survey in 2000).

cultivar	**NO_3-N**	**SO_4-S**	**Fe**	**Zn**	**Mn**	**Cu**
	.... µ g g^{-1}..............					
Rekord	437	104.2	61.27	44.72	10.41	11.30
Eposs	610	145.5	65.70	57.46	19.25	14.69
Bonlim	705	157.2	65.04	54.97	19.45	14.47
Vulkan	714	180.5	73.35	57.93	19.44	13.45
Mars	643	91.0	53.30	44.58	12.48	09.21
Rekord	519	58.6	77.44	45.66	13.59	10.99
Bonlim	613	41.3	81.60	47.82	17.68	07.71
H. leistungsauslese	905	39.6	75.79	53.92	16.08	11.28
Rekord	459	73.6	66.63	48.25	16.12	09.93
++	452	107.9	70.77	49.28	12.10	13.59
Huchels Alpha	492	82.3	69.47	47.46	13.32	11.15
Rekord	324	113.2	60.80	56.32	13.13	13.63
Horlim	316	160.8	78.08	52.05	12.37	13.46
Gijnlim	460	40.3	56.35	48.88	11.21	12.69
Gijnlim	197	111.6	63.14	46.81	12.27	11.78
++	545	54.9	59.46	47.59	14.47	11.07
S. Meisterschuss	552	48.3	65.44	44.64	12.76	12.26
S. Meisterschuss	511	65.3	63.27	59.39	13.83	13.23
S. Meisterschuss	505	99.2	63.77	55.48	17.28	13.62
Huchels Alpha	531	44.6	57.86	47.64	09.82	10.61
Huchels Alpha	689	56.6	65.52	58.54	10.17	12.27
Huchels Alpha	705	102.6	70.95	56.33	11.68	15.21
Huchels Alpha	683	96.9	74.49	50.61	10.81	16.31
++	338	52.9	60.76	49.97	20.39	12.69

Note: ++ unknown

Table 7-4: Macro-nutrient content of spear samples grown in Erfurt (field survey in 2000).

Samples	N	P	K	S	Ca	Mg
	mg g^{-1}					
1	37.2	3.89	29.78	5.92	2.96	1.09
2	42.6	4.13	30.78	5.44	2.67	1.00
3	43.5	5.29	45.49	8.58	4.11	1.25
4	48.4	4.32	32.02	5.55	2.94	1.02
5	42.8	3.58	25.93	4.15	2.26	0.80
6	44.7	4.18	33.05	5.78	2.73	0.93
7	43.3	3.98	30.23	5.89	2.87	0.86
8	46.4	3.90	28.47	5.45	2.56	0.77
9	45.3	4.05	30.78	5.88	2.73	0.89
10	47.3	3.69	25.61	5.08	2.55	0.80
11	46.5	3.70	25.56	4.91	2.4	0.72
12	47.5	3.86	27.49	5.10	2.39	0.79
13	44.5	3.80	26.38	5.02	2.45	0.79
14	45.7	3.48	24.47	4.25	2.06	0.68
15	46.2	3.39	25.36	4.53	2.10	0.61
16	46.6	3.67	25.66	4.86	2.52	0.67
17	44.3	5.30	--	--	--	1.10
18	42.9	3.79	26.73	4.98	2.42	0.81
19	43.9	3.86	30.93	5.65	2.20	1.01
20	44.7	3.49	25.20	5.07	2.29	0.35
21	44.9	3.66	27.21	5.11	1.64	0.87
22	44.9	4.02	32.62	6.27	1.79	0.96
23	39.9	3.55	26.07	4.66	1.61	0.78
24	42.1	3.52	24.62	4.75	2.09	0.78
25	37.6	3.42	26.37	4.34	2.09	0.77
26	42.8	3.58	26.08	4.75	2.35	0.79
27	44.2	3.38	22.10	4.24	1.39	0.75

Table 7-5: NO_3-N, SO_4-S and micro-nutrient content of spear samples grown in Erfurt (field survey in 2000).

Samples	NO_3-N	SO_4-S	Fe	Zn	Mn	Cu
	……………µg g^{-1}……………					
1	660	97.9	48.58	46.08	10.80	11.70
2	560	88.2	54.23	46.64	13.28	14.08
3	747	87.6	57.56	51.58	13.73	17.06
4	477	82.6	51.45	60.76	13.85	19.49
5	381	83.3	74.68	54.31	16.17	16.97
6	484	121.2	63.35	55.01	13.92	21.47
7	538	181.5	59.87	56.39	15.29	20.75
8	427	157.2	56.52	55.02	15.02	19.40
9	483	129.5	61.20	55.15	13.99	20.83
10	551	153.2	63.88	55.81	15.94	18.50
11	438	107.2	56.78	51.19	13.87	17.06
12	627	112.6	59.37	54.93	11.83	17.75
13	494	106.9	59.78	49.52	12.23	17.85
14	694	98.9	57.21	53.95	12.35	17.49
15	553	90.6	54.95	51.58	12.08	18.12
16	257	89.2	54.39	51.63	13.23	19.05
17	376	99.2	55.31	54.62	11.32	16.48
18	333	91.6	51.95	50.66	12.07	16.35
19	697	141.2	61.24	55.62	14.99	14.89
20	421	139.5	57.80	51.51	10.98	10.18
21	641	134.9	103.70	48.95	12.24	18.46
22	434	141.9	59.91	58.32	19.11	15.23
23	699	119.2	57.67	51.17	21.16	14.17
24	491	119.9	59.78	47.68	12.30	13.99
25	238	69.6	59.22	49.48	11.23	13.12
26	568	89.2	57.32	47.01	11.90	14.08
27	615	96.9	59.73	54.63	11.29	14.98

Table 7-6: Protein, glutathione and cysteine content of spear samples grown in Braunschweig and Erfurt (Field survey in 2000).

Sample	Braunschweig			Erfurt		
	Protein (%)	GSH (µg g^{-1})	Cysteine (µg g^{-1})	Protein (%)	GSH (µg g^{-1})	Cysteine (µg g^{-1})
1	26.6	9.53	4.46	23.3	29.95	3.08
2	29.6	8.67	6.07	26.6	26.34	1.97
3	28.8	10.01	3.37	27.2	11.69	2.64
4	28.8	31.79	3.50	30.3	13.10	3.41
5	23.4	22.01	5.72	26.8	12.14	3.23
6	26.4	18.31	5.90	27.9	10.01	5.50
7	25.2	25.74	5.80	27.1	29.00	3.38
8	28.3	9.29	9.41	29.0	8.23	3.21
9	22.4	9.61	4.69	28.3	26.63	3.23
10	29.3	10.31	3.72	29.6	8.08	7.27
11	25.7	24.51	2.95	29.1	32.05	3.96
12	27.6	5.59	4.31	29.7	25.10	5.66
13	25.3	30.08	5.80	27.8	16.64	6.69
14	25.6	27.84	4.53	28.6	8.15	7.39
15	26.7	28.77	2.45	28.8	8.28	5.35
16	26.0	30.07	2.81	29.1	7.17	5.37
17	28.7	17.35	6.31	27.7	27.97	4.31
18	27.8	8.41	2.87	26.8	28.22	2.90
19	24.7	27.28	9.40	27.4	30.39	4.75
20	24.4	31.91	2.87	27.9	29.56	5.98
21	26.8	27.98	4.57	28.1	7.17	7.39
22	26.4	25.39	2.91	28.1	7.65	7.39
23	27.3	28.47	3.68	24.9	32.43	3.26
24	25.9	25.49	6.86	26.3	25.01	4.95
25				23.5	30.85	3.11
26				26.75	6.65	6.19
27				27.62	26.98	5.50

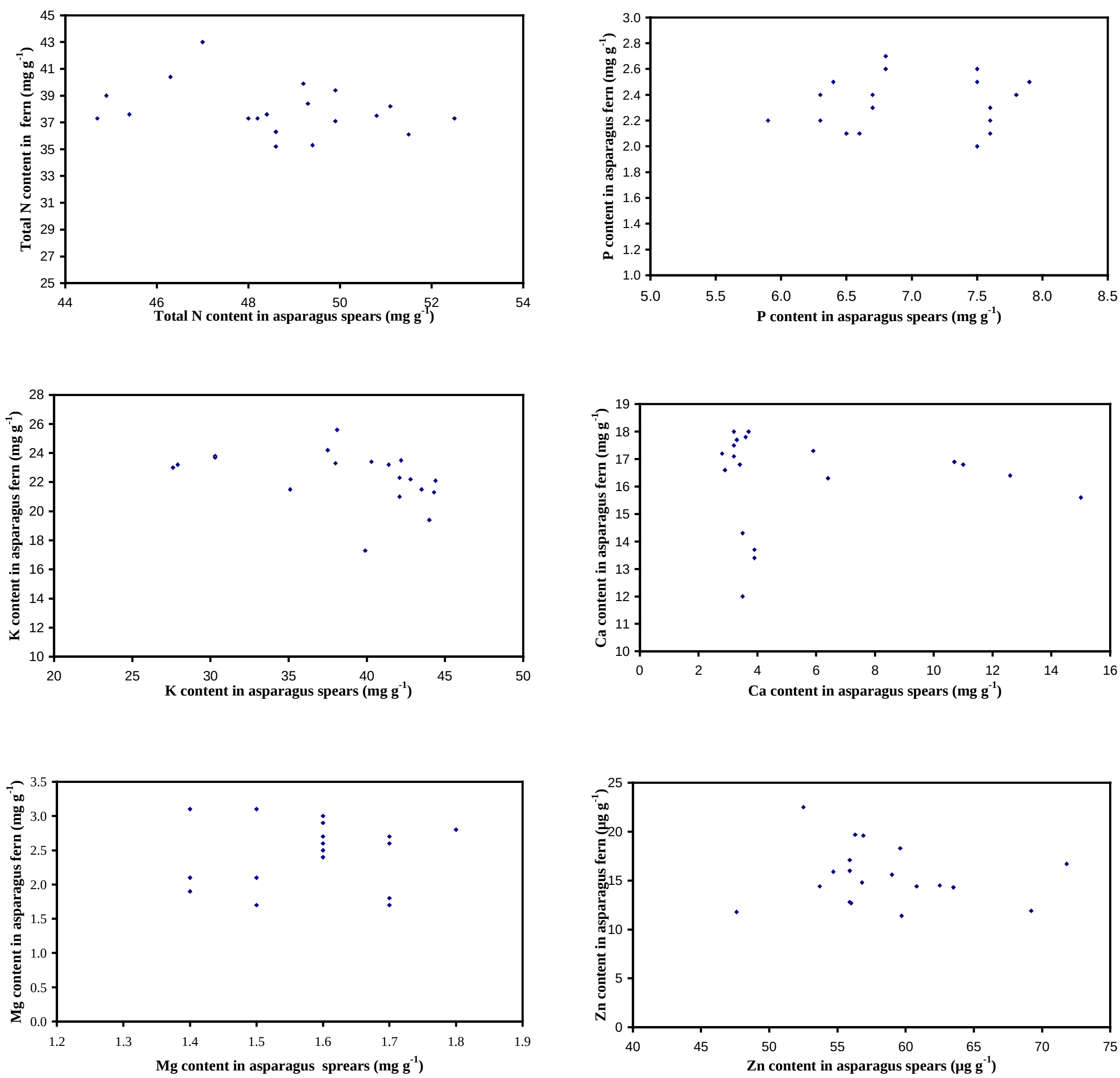


Fig. 7-1: Relationship between mineral content of asparagus spears and fern

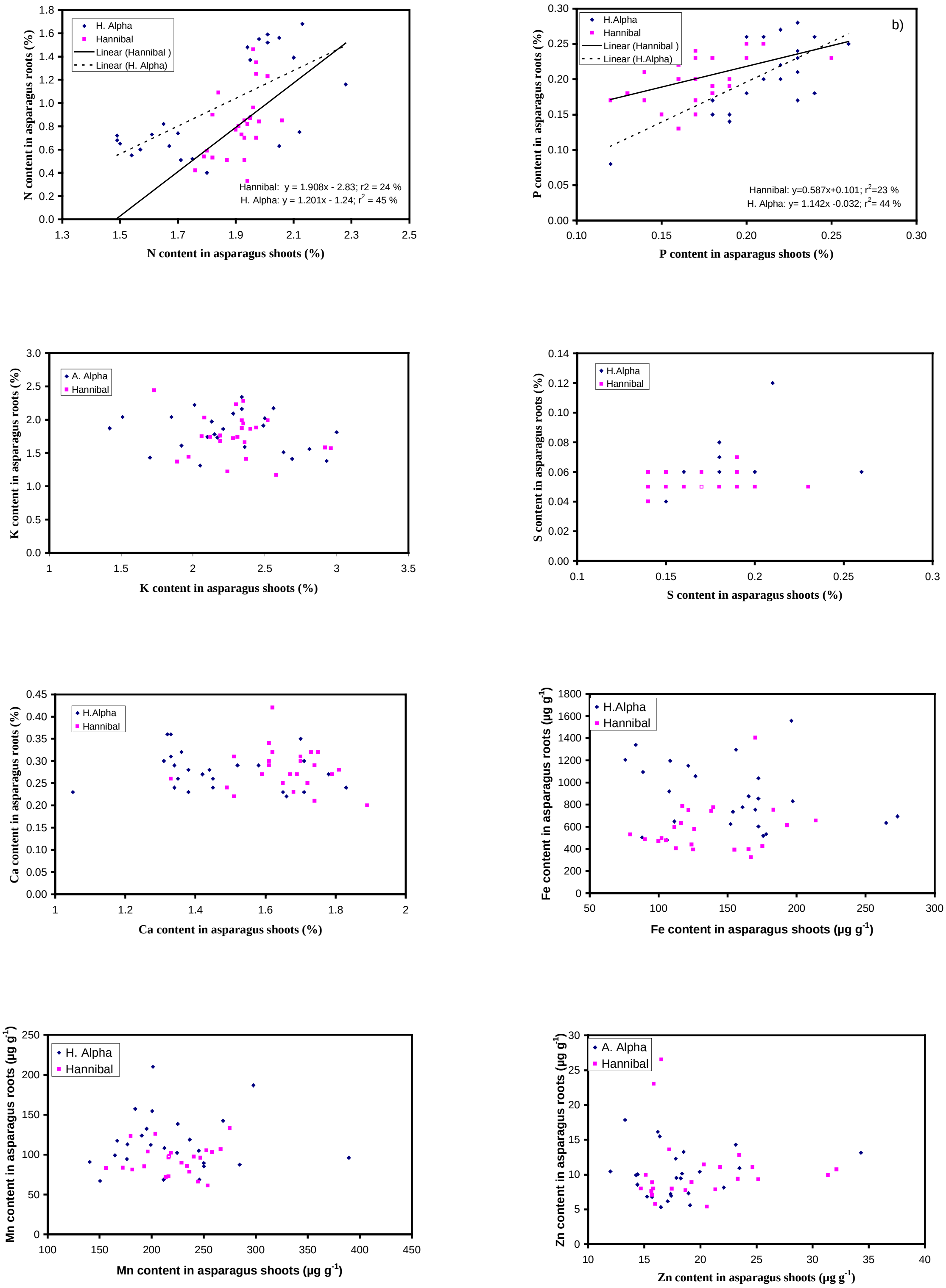
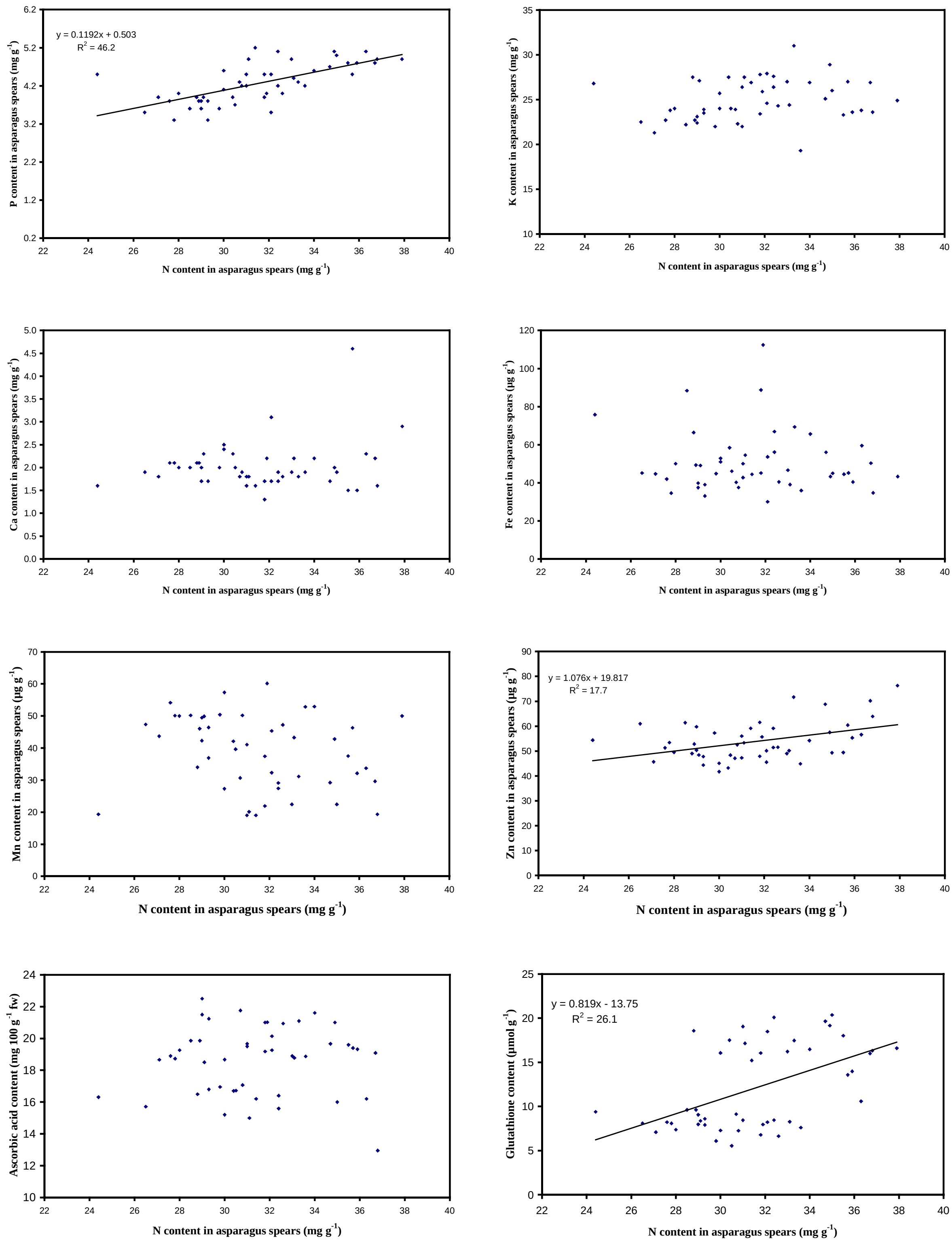


Fig. 7-2: Relationship between chemical composition in shoots and roots of transplants of two Asparagus cultuvars (*Huchels Alpha* and *Hannibal*) grown in pot experiment.



y = 0.1192x + 0.503
R2 = 46.2
P content in asparagus spears (mg g-1)
N content in asparagus spears (mg g-1)
K content in asparagus spears (mg g-1)
N content in asparagus spears (mg g-1)
Ca content in asparagus spears (mg g-1)
N content in asparagus spears (mg g-1)
Fe content in asparagus spears (µg g-1)
N content in asparagus spears (mg g-1)
Mn content in asparagus spears (µg g-1)
N content in asparagus spears (mg g-1)
y = 1.076x + 19.817
R2 = 17.7
Zn content in asparagus spears (µg g-1)
N content in asparagus spears (mg g-1)
Ascorbic acid content (mg 100 g-1 fw)
N content in asparagus spears (mg g-1)
y = 0.819x - 13.75
R2 = 26.1
Glutathione content (µmol g-1)
N content in asparagus spears (mg g-1)

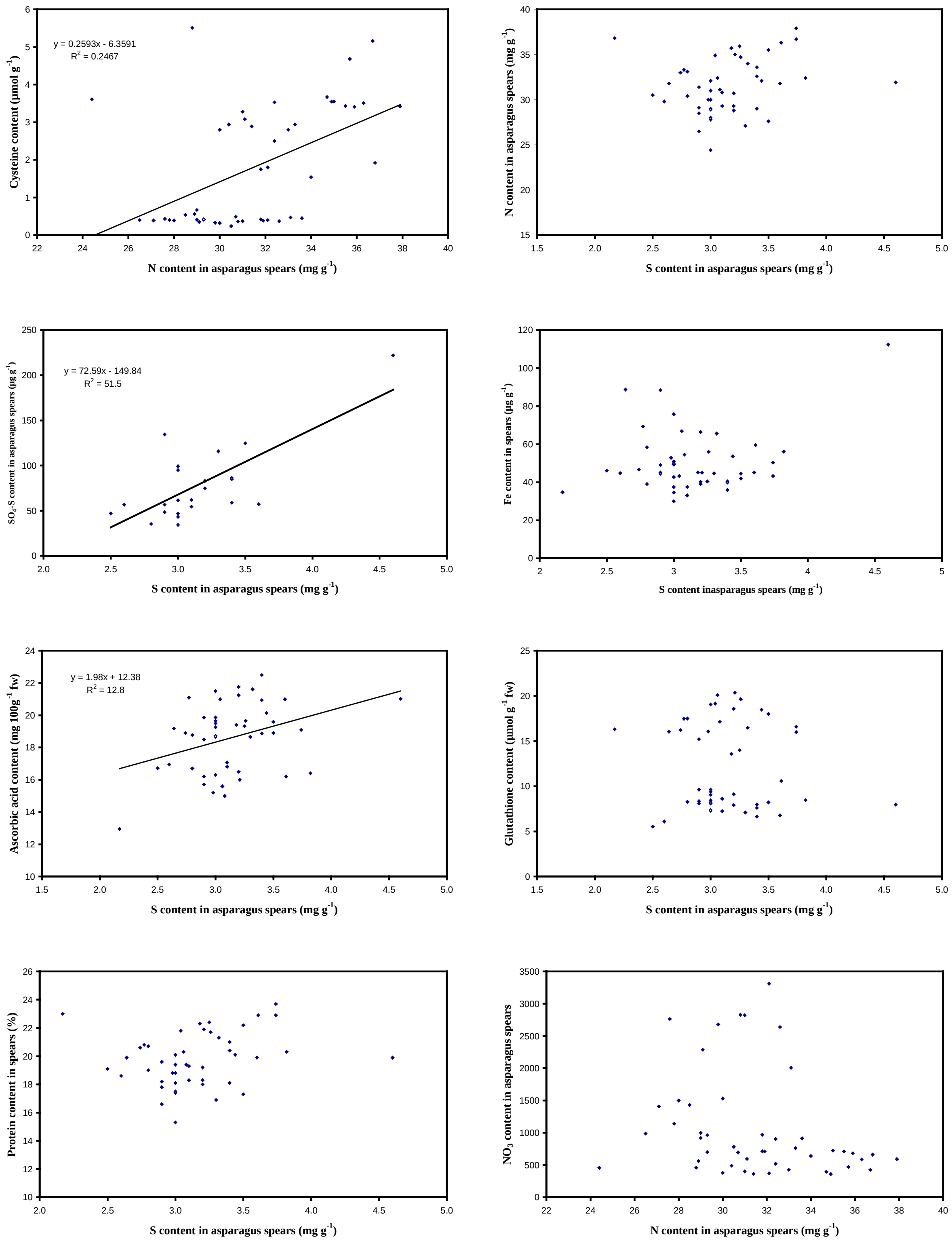


Fig. 7-3: Relationship between N and S content in asparagus spears and nutrient content in asparagus spears

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