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Wirkung des Anbaus von Zuckerrüben in Dämmen auf Bodenstruktur und Pflanzenwachstum unter norddeutschen Bedingungen

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Publikationen

Folgende Manuskripte der vorliegenden Dissertation wurden bereits publiziert oder sind für eine Publikation vorgesehen:

KRAUSE, U., KOCH, H.-J., SANDER, G., SCHLINKER, G. (2008): Yield formation of sugar beet cultivated on ridges at sandy and loessial sites in Northern Germany. Sugar Industry 133, 689-698.

KRAUSE, U., KOCH, H.-J., MÄRLÄNDER, B. (2008): Analysis of yield formation of sugar beet under ridge and flat cultivation. European Journal of Agronomy (submitted).

Abkürzungsverzeichnis

Abb.	Abbildung (Figure)
AC	Air Capacity (Luftkapazität)
AmN	α-amino-N-content (α-Amino-N-Gehalt)
BZE	Bereinigter Zuckerertrag (White Sugar Yield)
° C	Grad Celsius
cf	confer (vergleiche)
CGR	Crop Growth Rate (Wachstumsrate)
cm	Zentimeter
CT	Cultivation Technique (Anbauverfahren)
d	Day (Tag)
DM/ DMY	Dry Matter/ Dry Matter Yield (Trockenmasse/ Trockenmasseertrag)
€	Euro
E	East (Ost)
EG	Europäische Gemeinschaft
50 % FE_{rel}	50 % relative Field Emergence (50 % relativer Feldaufgang)
Fig.	Figure (Abbildung)
g	Gramm
h	Stunde
ha	Hektar
K	Kalium
kg	Kilogramm
km	Kilometer
kPa	Kilopascal
kW	Kilowatt
l	Liter
m	Meter
mm	Millimeter
MPa	Megapascal
N	North (Nord)
N	Stickstoff
Na	Natrium
N_{min}	soil mineral nitrogen (mineralischer Bodenstickstoff)
Nr.	Nummer

ns	not significant (nicht signifikant)
P	Phosphor
PR	Penetration Resistance (Eindringwiderstand)
r	Korrelationskoeffizient
r^2	Bestimmtheitsmaß
RLD	Root Length Density (Wurzellängendichte)
RY	Root Yield (Rübenertrag)
SC	Sugar Content (Zuckergehalt)
sd	Standardabweichung
SD	Sowing Date (Saattermin)
t	Tonne
Tab.	Tabelle (Table)
TT	Thermal time (Temperatursumme)
WSY	White Sugar Yield (Bereinigter Zuckerertrag)
p	Irrtumswahrscheinlichkeit
*	signifikant bei $p \leq 0,05$
**	signifikant bei $p \leq 0,01$
***	signifikant bei $p \leq 0,001$

Zusammenfassung

In der Pflanzenproduktion kann ein optimiertes Anbauverfahren dazu beitragen, das standortspezifische Ertragspotenzial auszuschöpfen. In der vorliegenden Arbeit wurde der Ertragseffekt des Dammanbaus von Zuckerrüben mit dem konventionellen Flachanbau verglichen. Von besonderem Interesse war dabei der Einfluss unterschiedlicher Bodenfeuchte bei der Aussaat auf wichtige bodenphysikalische und -chemische Bodenparameter und den Verlauf der Ertragsbildung bei Flach- und Dammanbau.

In den Jahren 2006 und 2007 wurden Feldversuche auf einem Sand- und Lössstandort in Norddeutschland durchgeführt und die Parameter Bodentemperatur und -wassergehalt, mineralischer Bodenstickstoff, Eindringwiderstand und Luftkapazität des Bodens erhoben. Zur Ermittlung des Zusammenhanges von Bodenparametern und dem Verlauf des Pflanzenwachstums wurde der Feldaufgang erfasst, die Wurzellängendichte gemessen, Zeiternten durchgeführt und absolute Wachstumsraten bestimmt. Ertrags- und Qualitätsparameter sowie der Gehalt an Stickstoff, Kalium und Phosphor in den Pflanzen wurden ermittelt.

Der Dammanbau von Zuckerrüben stellt eine Möglichkeit dar, den Rübenertrag gegenüber dem Flachanbau zu steigern. Ein höherer Rübenertrag wurde bei Damm- im Vergleich zum Flachanbau erzielt, wenn die Bodentemperatur in der Auflaufphase und Jugendentwicklung durch die Dammformung deutlich erhöht war (0,5-1 °C). Die höhere Bodentemperatur im Dammanbau beschleunigte den Feldaufgang und das Jugendwachstum der Zuckerrübe. Der wachstumsfördernde Effekt der Temperaturerhöhung durch den Damm war umso größer, je niedriger das Ausgangsniveau der Bodentemperatur war. Bei hohem Niveau der Bodentemperatur von deutlich über 10 °C führte der Dammanbau nicht zu einer Ertragssteigerung. Den größten Einfluss auf das Wachstum der Zuckerrübe hatte die Bodentemperatur in dem Zeitraum von der Aussaat bis zum 4-6-Blattstadium. Infolge des sich entwickelnden Blattapparates und der dadurch zunehmenden Bodenbeschattung ging der Einfluss der Bodentemperatur danach zurück und die Bedeutung des

Eindringwiderstandes für das Pflanzenwachstum stieg an. Nach dem Reihenschluss im Juni war der Verlauf des Zuckerrübenwachstums bei Flach- und Dammanbau gleich. Die vorgestellten Ergebnisse zeigen, dass die Grundlage des höheren Rübenertrages im Dammanbau während der Jugendentwicklung gebildet wurde und in einem Mehrertrag von 7-9 % gegenüber dem Flachanbau resultierte.

Der Einfluss einer hohen Bodenfeuchte gegenüber einer um mehrere Tage verzögerten Aussaat bei niedrigerer Bodenfeuchte erhöhte den Trockenmasseertrag bis zum Reihenschluss, beeinflusste jedoch den Rübenertrag im Herbst nicht. Eine Bearbeitung und Aussaat bei hoher Bodenfeuchte kann auf Lössstandorten die Ausbildung einer verschlämmten und verkrusteten Oberfläche nach sich ziehen, die den Feldaufgang und das Jugendwachstum behindern kann. Daher sind keine Vorteile durch eine Vorverlegung des Saatzeitpunktes im Dammanbau bei Bedingungen mit hoher Bodenfeuchte zu erwarten, wenn zum standortspezifisch optimalen Saattermin sichergestellt ist, dass der Wasserbedarf der Samen für Keimung und Feldaufgang gedeckt wird.

Die Wirkung von Anbauverfahren und unterschiedlicher Bodenfeuchte bei der Aussaat auf die Luftkapazität und den Gehalt an mineralischem Stickstoff im Boden sowie die Nährstoffversorgung der Pflanzen beeinflusste den Rübenertrag vermutlich nicht.

Unterschiede in der Höhe des Ertragseffektes durch Dammanbau zwischen Sand- und Lössböden bestehen offensichtlich nicht. Jedoch ist davon auszugehen, dass geringere Ertragsunterschiede in Regionen mit einer wärmeren Frühjahrswitterung als am Versuchsstandort auftreten.

Für die Evaluierung des Dammanbaus von Zuckerrüben müssen der zu erwartenden Ertragssteigerung die höheren Kosten gegenüber gestellt werden. Möglichkeiten der maschinen- und verfahrenstechnischen Weiterentwicklung des Dammanbaus, wie das Vorziehen der Dammformung in den Herbst, sollten dabei Beachtung finden.

Summary

An optimised crop management can help to utilise the site-specific yield potential in crop production. This study aimed to compare the influence of conventional flat and ridge cultivation on sugar beet yield. The effect of different soil moisture conditions at sowing on soil physical and chemical properties relevant for sugar beet growth and yield formation in flat and ridge cultivation was of particular interest.

In 2006 and 2007 field trials were conducted at a site with sandy and loessial soil in Northern Germany. Data of temperature, water content, mineral nitrogen, penetration resistance and air capacity of the soil were collected. Field emergence, root length density, intermediate harvests and absolute crop growth rates were determined for evaluating the influence of soil characteristics on plant growth. Furthermore, yield and quality parameters as well as total nitrogen, phosphorus and potassium concentration of plants were analysed.

Higher root yield of sugar beet can be obtained by ridge compared to conventional flat cultivation. Data revealed higher root yield for ridge compared to flat cultivation, if soil temperature during field emergence and early growth was substantially increased by ridge forming (0.5-1 °C). The increased ridge soil temperature enhanced field emergence and early growth of sugar beet. The growth enhancing effect of temperature increase by ridge cultivation can be expected as high, if the base level of soil temperature is low. When sugar beet was sown at a soil temperature considerably above 10 °C, ridge cultivation did not enhance growth. From sowing to 4-6-leaf-stage, soil temperature appeared to be the most effective factor determining sugar beet growth. Due to soil shading by the evolving leaf canopy during early growth until June, impact of soil temperature on sugar beet growth declined and the importance of penetration resistance increased. After canopy closure in June sugar beet growth was not different between flat and ridge cultivation. Conclusively, the basis of higher final yield in ridge cultivation was established during early growth and increased root yield by 7-9 % compared to flat cultivation.

Spring tillage and sowing conducted at high soil moisture compared to a several days delayed sowing at lower soil moisture level increased total plant dry matter yield at May and June harvest, but did not influence final root yield. At loessial soil, tillage and sowing at high soil moisture is a risk to cause a sealed and crusted soil surface, impairing field emergence and subsequent plant growth. Thus, a preponed sowing date at high soil moisture does not give any advantage to ridge cultivation, if the seedlings' water requirement for germination and field emergence is fully met at the site-specific optimal sowing date.

The effect of cultivation technique and different soil moisture conditions at sowing on air capacity, soil mineral nitrogen and nutrient supply of sugar beet had probably no influence on root yield.

Differences between sandy and loessial soils in the magnitude of yield increase obtained from ridge cultivation do apparently not exist. However, smaller yield differences between cultivation techniques are expected in regions with warmer spring temperatures.

For an evaluation of ridge cultivation of sugar beet, the potential yield increase has to be balanced against the higher costs. Advancing of machinery and cultivation technique of ridge cultivation, e.g. forward ridge forming in autumn, should be considered.

1. Prolog

Die Anbaufläche sowie die Erlöse im Zuckerrübenanbau sinken infolge der Umsetzung der Reform der europäischen Zuckermarktordnung. Nach Verordnung (EG) Nr. 318/2006 wurde der Mindestpreis für Zuckerrüben von 46,72 € t^{-1} für A-Rüben auf nur 29,80 € t^{-1} im Zuckerwirtschaftsjahr 2007/2008 abgesenkt (ANONYM 2006). Eine Verwendung frei gewordener Anbaufläche zum Anbau von Zuckerrüben zur Bioethanolproduktion ist aufgrund der hohen europäischen Produktionskosten nur für zuckerfabriknahe Standorte (NOLTE und GRETHE 2008) und unter der Aufrechterhaltung von EU-Schutzzöllen gegenüber Bioethanolimporten eine Alternative. Ein weiterer Anteil der zurückgehenden Zuckerrübenanbaufläche wird zunehmend durch Industrierüben ersetzt, deren Preis jedoch unter dem für Quotenrüben liegt und regional stark schwankt (DNZ 2008, VSZ 2008). Parallel zu dieser Entwicklung wurden in 2007 sehr hohe Preise von bis zu 280 € t^{-1} für Weizen und 420 € t^{-1} für Rapssaat erzielt (SCHUMACHER und STRIEWE 2008) und dadurch die Anbauwürdigkeit dieser Kulturen enorm gesteigert. Auch in Anbetracht der aktuell wieder stark rückläufigen Preisentwicklung für Getreide und Ölfrüchte geht die bisher überdurchschnittlich hohe Attraktivität des Zuckerrübenanbaus zurück und andere Blattfrüchte wie Raps und Mais ersetzen teilweise oder völlig die Zuckerrübe in der Fruchtfolge. Die Ausschöpfung des standortspezifischen Ertragspotenzials ist vor diesem Hintergrund von besonderer Bedeutung. Neben dem züchterischen Fortschritt und einer verbesserten Düngungs- und Pflanzenschutzstrategie kann ein optimiertes Anbauverfahren dazu beitragen, den Ertrag zu erhöhen. Für den Zuckerrübenanbau könnte der Anbau im Damm einen Beitrag dazu leisten, dieses Ziel zu erreichen.

In Norddeutschland wurden bei ersten Anbauvergleichen des standorttypischen Flachanbaus von Zuckerrüben mit dem Dammanbau Mehrerträge von bis zu 10 % erreicht (SCHLINKER et al. 2007). Um langfristig einen höheren Ertrag durch den Dammanbau erzielen zu können, ist die Kenntnis der wachstumsfördernden Mechanismen und wann diese wirksam werden sowie deren gezielte Nutzung durch die Anbaugestaltung von entscheidender Bedeutung.

Jedoch ist der Einfluss von Dammformung und -anbau auf wachstumsrelevante Bodenparameter und deren Auswirkung auf den Verlauf des Zuckerrübenwachstums derzeit weitgehend unklar.

Der Anbau von Zuckerrüben im Damm ist in Deutschland noch weitgehend unbekannt. Dementsprechend wenige Kenntnisse und Erfahrungen liegen für die standortangepasste Anbaugestaltung vor. Bislang ist der Dammanbau hierzulande vor allem für Kartoffeln, Spargel und Möhren von Bedeutung. Der Anbau landwirtschaftlicher Kulturen im Damm ist weltweit verbreitet und weist vielfältige Formen auf. In den USA ist der Dammanbau als eine Form der konservierenden Bodenbearbeitung zu Mais und Sojabohne etabliert (ECKERT 1990, REEDER 1990, UNGER und MUSICK 1990, PIKUL JR. et al. 2001). In anderen Ländern ist besonders die Konservierung von Bodenwasser (HULUGALLE 1990, JONES und STEWART 1990) und der Schutz vor Winderosion (LIU et al. 2006) von großer Bedeutung. In der ökologischen Landwirtschaft erleichtern Dammkulturen die Durchführung von Maßnahmen der mechanischen Unkrautregulierung (LAL 1990, QUINTERN 2005). Der Dammanbau von Zuckerrüben war bis zur Aufgabe des Zuckerrübenanbaus in Irland weit verbreitet. Momentan wird der Dammanbau von Zuckerrüben vor allem in Kalifornien angewendet, wo der Wasserbedarf der Pflanzen über Furchenbewässerung kostengünstig gedeckt wird (HILLS et al. 1995, SCHWARTZ 1996).

In den in Deutschland bisher durchgeführten Praxisvergleichen wurde festgestellt, dass Keimung und Feldaufgang im Dammanbau zügiger einsetzen und dadurch die Jugendentwicklung gefördert wird. Vermutlich erhöht die infolge der Dammformung vergrößerte Bodenoberfläche (SHARRATT et al. 1992) und der günstigere Einfallswinkel der Sonnenstrahlung an den Dammschenkeln die Strahlungsabsorption und beeinflusst damit den Wasser- und Temperaturhaushalt im Damm (BENJAMIN et al. 1990). Ein weiterer Einfluss auf die thermischen Eigenschaften im Boden ist von der intensiven Bodenlockerung während der Dammformung zu erwarten, bei der die räumliche Verteilung und die volumenbezogenen Anteile von Wasser, Luft und festen Bodenpartikeln verändert werden (LEXANDER 1993, USOWICZ et al. 1996). Luft besitzt eine vielfach geringere Wärmekapazität als Wasser und trägt damit zur schnelleren Erwärmung des Bodens bei (GUÉRIF et al. 2001). Zudem ist bekannt, dass hohe Bodentemperaturen und intensive Bodenbearbeitung die N-Mineralisation und damit das Pflanzenwachstum anregen (HASSINK 1992, SILGRAM und SHEPHERD 1999). Diese komplexen Zusammenhänge könnten ursächlich für die beobachteten Ertragssteigerungen im Dammanbau sein, wurden jedoch bislang nicht detailliert beschrieben.

Die höchste photosynthetisch aktive Strahlung wird im Jahresverlauf zwischen April und September erreicht. Jedoch kann die Zuckerrübe aufgrund einer relativ späten Aussaat, der langsamen Jugendentwicklung und geringen Blattfläche im Frühjahr diese Strahlung nicht ausreichend für die Ertragsbildung ausschöpfen (SCOTT und JAGGARD 1978, KENTER et al. 2006). Eine zeitige Aussaat der Zuckerrübe im Frühjahr und eine zügige Jugendentwicklung kann dazu beitragen, den optimalen Blattflächenindex von etwa 4 möglichst schnell zu erreichen und die Strahlungsabsorption besser zu nutzen (SCOTT und JAGGARD 1993, RÖVER 1995). Eine Aussaat nach dem standortspezifisch optimalen Saattermin ist mit einer Zunahme der Verluste des Bereinigten Zuckerertrages verbunden (MÄRLÄNDER 1991).

Zur Aussaat im Frühjahr müssen die nach dem Winter nassen Böden eine hinlängliche Abtrocknung aufweisen, um Bodenverdichtungen während der Saatbettbereitung zu verhindern und ein günstiges Bodengefüge für die Keimung der Zuckerrübenpillen zu gewährleisten. Die optimale Bodenfeuchte zur Aussaat ist im Dammanbau, aufgrund der intensiveren Abtrocknung des Bodens nach der Dammformung, vermutlich höher als bei Flachanbau. Dennoch birgt eine Aussaat bei hoher Bodenfeuchte das Risiko von Verdichtungen inner- und unterhalb des Saathorizontes (KOOISTRA 1989, RICHARD et al. 1999) mit möglicherweise ertragsmindernder Wirkung (JAGGARD 1977). Bei bereits stark abgetrockneten Böden und warm-trockener Witterung besteht die Gefahr, dass der Damm nach der Dammformung austrocknet. Die Wasserversorgung der Samen für Quellung und Keimung und schließlich die Bestandesetablierung kann dadurch beeinträchtigt werden

(AKESON et al. 1980, SCHLINKER et al. 2007). Die Wahl des Anbauverfahrens Flach oder Damm könnte daher einen entscheidenden Einfluss auf den ortsspezifisch optimalen Saattermin der Zuckerrübe und die damit verbundene Ausnutzung des Ertragspotenzials ausüben.

Als Ursache für Ertragsunterschiede beim Vergleich der Anbauverfahren Flach und Damm in unterschiedlichen Regionen Deutschlands wurde von SCHLINKER et al. (2007) der Einfluss von Klima und Standort vermutet. In den Regionen Ostwestfalen und Uelzen-Holstein konnte der Ertrag durch den Dammanbau erhöht werden, während im Rheinland kein Mehrertrag erzielt wurde. Das Rheinland ist durch höhere Temperaturen und geringere Niederschläge als die nördlicher gelegenen Regionen Ostwestfalen und Uelzen-Holstein gekennzeichnet und möglicherweise konnten die Zuckerrüben im Damm daher nicht von den Effekten des Dammanbaus profitieren. Zusätzlich könnte auch die Bodenart die Eignung eines Standortes für den Dammanbau von Zuckerrüben wesentlich beeinflussen. Eine geringe Feldkapazität, niedrige Wasserleitfähigkeit und ein hoher Grobporenanteil im Boden könnten unter trockenen, warmen Bedingungen die Austrocknung des Dammes begünstigen und das Pflanzenwachstum beeinflussen.

Die vielfältigen Aspekte und Fragestellungen im Zusammenhang mit dem Dammanbau von Zuckerrüben wurden in einem zweijährigen Feldversuch auf einem Sand- und einem Lössstandort in Norddeutschland (Region Uelzen) untersucht. Im Mittelpunkt stand dabei die Frage, wie die Anbauverfahren Flach und Damm sowie die Aussaat bei unterschiedlich feuchten Bodenbedingungen wichtige Bodeneigenschaften und den Verlauf der Ertragsbildung beeinflussen. Es wurde geprüft, welche Faktoren Ertragsunterschiede bewirken und wann diese gebildet werden. Weiterhin wurde der Frage nachgegangen, ob der optimale Saattermin im Dammanbau früher als bei Flachanbau liegt.

Die Ergebnisse werden nachfolgend in drei Artikeln vorgestellt. Der erste Artikel „Yield formation of sugar beet cultivated on ridges at sandy and loessial sites in Northern Germany“ wurde in der Zeitschrift „Zuckerindustrie/Sugar Industry 133, 689-698“ veröffentlicht. In deutscher Sprache erfolgte die Publikation unter dem Titel „Ertragsbildung von Zuckerrüben bei Dammanbau auf Sand- und Lössböden in Norddeutschland“ in einem Sonderdruck der Zeitschrift „Zuckerindustrie/Sugar Industry 133, 75-85“ zur 8. Göttinger Zuckerrübentagung 2008. Gegenstand dieses Artikels ist der Einfluss des Anbauverfahrens auf Ertrag und Qualität der Zuckerrübe. Zusätzlich wird aufgezeigt, wie sich die Aussaat zu Terminen mit unterschiedlicher Bodenfeuchte sowie die Bodenart auf Bodenstruktur und Ertragsparameter auswirken. Die Ergebnisse zeigen, dass der Dammanbau die Bodentemperatur während des Feldaufgangs und der Jugendentwicklung der Zuckerrübe erhöhte und die Bodenfeuchte verringerte. Bei für Zuckerrüben üblicher Aussaat Ende März/Anfang April und einer Bodentemperatur unter 10 °C beschleunigte der Dammanbau den Feldaufgang und erhöhte den relativen Mehrertrag im Herbst um 7-8 % gegenüber dem Flachanbau. Eine Aussaat Anfang Mai unter deutlich höherer Temperatur förderte das Zuckerrübenwachstum im Dammanbau nicht. Die Qualität der Zuckerrübe blieb durch das Anbauverfahren weitgehend unbeeinflusst. Ein ertragswirksamer Einfluss der Bodenfeuchte bei der Aussaat auf die Bodenstruktur und das Pflanzenwachstum in den Anbauverfahren Flach und Damm konnte nicht festgestellt werden, ebenso unterschieden sich Sand- und Lössböden nicht in ihrer Ertragsreaktion.

Im zweiten Artikel mit dem Titel „Analysis of yield formation of sugar beet under ridge and flat cultivation”, eingereicht beim „European Journal of Agronomy“, erfolgt eine detaillierte Wachstumsanalyse der Zuckerrübe zu verschiedenen Entwicklungsphasen. Die Wirkungen der Anbauverfahren Flach und Damm auf wachstumsrelevante Bodenparameter kann im Verlauf der Vegetationsperiode variieren und die Ertragsbildung beeinflussen. Die Ertragsentwicklung der Zuckerrübe wurde untersucht und der für eine Entwicklungsphase maßgeblich prägende Bodenparameter herausgestellt. Höhere Wachstumsraten im Damm- als im Flachanbau wurden während der Jugendentwicklung bis zum Reihenschluss im Juni festgestellt, dagegen traten in der zweiten Hälfte der Vegetationsperiode bis zur Endernte im Oktober keine signifikanten Unterschiede auf. Grundlage für den um 8,4 % höheren

Endertrag im Dammanbau waren die höheren Wachstumsraten bis zum Reihenschluss, verursacht durch eine höhere Bodentemperatur und eine günstigere Bodenstruktur im Damm.

Den Artikeln folgt im Epilog eine weitere Untersuchung zum Anbau von Zuckerrüben im Herbstdamm als eine Variation des zuvor thematisierten Dammanbaus im Frühjahr. Es wird geprüft, inwieweit die Vorverlegung der Dammformung in den Herbst dazu beitragen kann, die derzeitig geringe Effizienz des Verfahrens zu steigern und dennoch die ertragserhöhende Wirkung des Dammanbaus zu nutzen. Im Mittelpunkt der Betrachtungen steht der Einfluss einer frühen (September) und einer späten (November) Formung des Herbstdammes auf die Bodentemperatur, den Feldaufgang und den Ertrag im Vergleich zum Verfahren Flach und dem Dammanbau im Frühjahr. Eine Erhöhung der Bodentemperatur und ein zügigerer Feldaufgang in den im Herbst sowie im Frühjahr gezogenen Dämmen gegenüber der flachen Bodenoberfläche wurde festgestellt. Der Ertragsunterschied zwischen den Varianten zur Endernte im Oktober war nicht eindeutig signifikant, jedoch war der Bereinigte Zuckerertrag im Verfahren Herbstdamm ähnlich dem bei Dammanbau im Frühjahr und lag im Mittel um 6,8 % über dem Ergebnis des Flachanbaus. Die Veröffentlichung der einjährigen Ergebnisse in einer praxisnahen Zeitschrift ist vorgesehen und soll dazu beitragen, die Bekanntheit und Verbreitung des Dammanbaus von Zuckerrüben in Deutschland zu steigern und Anpassungsmöglichkeiten des Verfahrens aufzuzeigen.

In einem abschließenden Fazit werden die wichtigsten Ergebnisse dieser Arbeit vorgestellt. Wachstumsfaktoren, die zum Erzielen eines höheren Ertrages bei Damm- gegenüber dem Flachanbau nötig sind, werden definiert und die für die Bildung des Mehrertrages entscheidenden Entwicklungsphasen eingegrenzt. Die aktuelle Verbreitung und Perspektive des Dammanbaus von Zuckerrüben in Deutschland wird besprochen.

2. Yield formation of sugar beet cultivated on ridges at sandy and loessial sites in Northern Germany

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Abstract

Field trials were conducted in 2006-2007 at sandy and loessial sites of the Uelzen region (Lower Saxony, Northern Germany) to elucidate the influence of ridge compared to flat cultivation of sugar beet on soil physical properties and crop growth. Between sowing and 4-6-leaf-stage, mean daily soil temperature in 3-5 cm soil depth was up to 1.4 °C higher while the water content in 0-15 cm depth was about 5 m^3 100 m^{-3} lower in ridge compared to flat cultivated soil. Thereupon, field emergence of sugar beet was up to 3 days faster and total plant yield at 4-6-leaf-stage increased up to 45 %, when sowing was conducted by the end of March/beginning of April at a soil temperature substantially below 10 °C. Until autumn, relative yield increase due to ridge cultivation diminished to 7-8 %. When sugar beet was sown in the beginning of May at considerably higher temperatures, ridge cultivation did not enhance sugar beet growth. A relevant effect of high soil moisture at sowing on soil structure and plant growth was not detected. Yield effect of ridge cultivation did not differ between sandy and loessial soils. For comprehensive evaluation of ridge cultivation of sugar beet, the higher inputs of energy and machinery for ridge forming have to be taken into account.

Keywords: ridge cultivation, plant growth, soil type, field emergence, soil temperature, soil water content, soil structure

1 Introduction

All over the world, there is a remarkable variety in ridge cultivation systems, each of which is specifically adjusted to the priority objective. Ridge cultivation is established as a form of conservation tillage for maize and soybean (*Eckert*, 1990; *Reeder*, 1990; *Unger* and *Musick*, 1990; *Pikul Jr.* et al., 2001), for conservation of soil water (*Hulugalle*, 1990; *Jones* and *Stewart*, 1990) and erosion control (*Liu* et al., 2006). In organic farming, several crops are cultivated on ridges for an easier weed control (*Lal*, 1990; *Quintern*, 2005). Ridge cultivation of sugar beet was practiced on a large scale in Ireland until cultivation of this crop completely ceased there a few years ago. Currently, ridge cultivation of sugar beet is widely applied in California (USA), where the crop’s water demand is cost-efficiently met by furrow irrigation (*Hills* et al., 1995).

In Germany, crops grown on ridges are potatoes, asparagus and carrots, whereas ridge cultivation of sugar beet is hardly known. Since 1999, on-farm trials with ridge cultivation of sugar beet have been conducted on marsh soils in Dithmarschen (Schleswig-Holstein), which are characterised by slow soil warming in spring. Thereby, ridge compared to site-specific flat cultivation enhanced early growth and increased yield by about 10 % (*Grape*, 2002; *Grape* et al., 2004). In other regions of Germany with different soil and climatic conditions, performance of ridge cultivation is still under examination (*Schlinker* et al., 2007).

Currently, competition between leaf crops such as rapeseed, maize and sugar beet necessitates to utilise the site-specific yield potential by optimising crop management. In sugar beet, ridge cultivation provides the opportunity to better reach this target. Knowledge of how ridge cultivation of sugar beet helps to overcome constraints for crop growth and yield formation is necessary to guarantee higher yields in the long-term and for a systematic use of ridge cultivation in crop management. Yet, limited data from on-farm trials on the effect of sugar beet ridge cultivation on final yield are available (*Schlinker* et al., 2007). The influence of ridge cultivation technique on soil physical parameters and sugar beet growth patterns during the growing season is widely unknown.

The previous on-farm trials revealed that ridges may become subject to soil desiccation in dry periods subsequent to ridge forming and sowing. Thus, water supply of seeds for imbibing and germination may be impaired (*Akeson* et al., 1980) increasing the risk of poor crop establishment (*Schlinker* et al., 2007). Ridge forming and sowing under high soil moisture would eliminate this threat, but hold the risk of soil compaction within and underneath the seed horizon (*Kooistra*, 1989; *Richard* et al., 1999), which may impair crop growth (*Jaggard*, 1977).

Against this background, our study focuses on how ridge forming and sowing under very moist and moist soil conditions affects soil properties relevant for sugar beet growth and yield formation. The study based on the hypothesis that faster warming of the ridge soil in spring enhances field emergence, accelerates early plant growth and increases final yield compared to conventional flat cultivation. Furthermore, we examined how variation of soil moisture at high soil moisture level during ridge forming influences soil structure and crop growth.

To address these questions, field trials were conducted on a sandy and a loessial soil in 2006 and 2007. Further on, in 2005-2007 numerous on-farm trials were established on typical Northern German sandy and loessial sites to evaluate whether different soil types differ in suitability for ridge cultivation of sugar beet.

2 Material and Methods

2.1 Plot experiments

2.1.1 Experimental sites and layout

In 2006 and 2007, field experiments were established on two sites (Suderburg, Natendorf) near Uelzen, Lower Saxony, Germany. The experimental sites were located 35 km apart from each other and differed substantially in soil properties. In Suderburg, the soil was a loamy sand (Stagnic Cambisol; 30 g kg^{-1} clay, 160 g kg^{-1} silt, 810 g kg^{-1} sand), in Natendorf the soil was a silty loam (Stagnic Luvisol; 100 g kg^{-1} clay, 690 g kg^{-1} silt, 210 g kg^{-1} sand) (*Ad-*

Hoc-AG Boden, 2005). Long-term means of annual temperature and precipitation in the Uelzen region was 8.7 °C and 685 mm, respectively.

The crops previous to sugar beet were winter cereals followed by white mustard or fodder radish as a catch crop (Tab.1). Straw and catch crop residues remained on the field. The catch crop was established with ploughless tillage techniques; catch crop material was either rolled or mulched before winter.

The cultivation technique was either flat (F) or ridge (R) treatment. Seedbed preparation was performed 14 cm deep immediately before ridge forming/sowing with a disc harrow or a rigid tine cultivator (Tab. 1). Ridges were formed with a six-row ridge former with Diabolo rolls (Struik BV, Wieringermeer, NL): a rotor loosened and lifted the soil, following metal sheets and rollers formed and compressed the ridges. The sowing machine was attached to the ridge former, accordingly ridge forming and sowing were conducted in one pass. The ridge top was elevated about 9 cm above the previous soil surface, ridge height was about 15 cm. In flat cultivation treatment, a conventional 18-row seeder was used for sowing. For both cultivation techniques, seed distance was 18 cm and row width 50 cm.

Cultivation and ridge forming/sowing were performed at two dates, which were determined site specifically according to sensory evaluation of soil moisture by an experienced field manager: sowing date 1 was early when the soil was trafficable but appeared too wet for optimal flat cultivation of sugar beet (F1, R1); at sowing date 2, the soil was clearly drier than at sowing date 1 but still moist (F2, R2). The time interval between sowing dates was 2-18 days depending on year and site (environment) (Tab.1).

After analysis of soil mineral nitrogen (N_{min} 0-90 cm; *Mengel*, 1991) in early spring, nitrogen fertiliser was applied up to 140 kg N ha^{-1}(*LWK Niedersachsen*, 2008), taking previous catch crop cultivation into account. Amount of fertiliser was equal in both cultivation technique treatments. Fertiliser was applied as ammonium nitrate urea solution at sowing date 1 including plots of sowing date 2. Further field management was conducted uniformly in each environment according to approved regional standards. In Suderburg, irrigation was applied according to plant requirements and soil water availability (2006: 150 mm applied in five doses from June to September; 2007: 27 mm given once in April).

At each site, a randomised Latin rectangle design with four replicates was established. Plot size was 9 m in width and 12 m in length. Rows and ridges were orientated in north-south direction.

Tab. 1: Field management and sampling dates during the study period in 2006 and 2007 in Suderburg and Natendorf; FC = field capacity.

	Suderburg		Natendorf	
Field management	2006	2007	2006	2007
Previous crop	Winter rye	Winter triticale	Winter wheat	Winter wheat
Catch crop	White mustard	White mustard	Fodder radish	White mustard
Seedbed preparation	Disc harrow 14 cm deep		Rigid tine cultivator 14 cm deep	
Sowing date 1	29.03.	15.03.	4.5.	15.03.
FC (%) in 0-15 cm	110	87	106	91
Sowing date 2	06.04.	29.03.	6.5.	02.04.
FC (%) in 0-15 cm	100	84	99	84
	Suderburg		Natendorf	
Sampling	2006	2007	2006	2007
Field emergence	18.04.-04.05.	04.04.-30.04.	11.05.-21.05.	04.04.-30.04.
Penetration resistance	20.04.	15.05.	29.05.	10.05.
FC (%) in 0-15 cm	75	85	81	67
Harvest 4-6-leaf-stage	15.05.	14.05.	09.06.	14.05.
Harvest canopy closure	15.06.	12.06.	28.06.	12.06.
Harvest August	15.08	14.08.	15.08.	14.08.
Harvest October	10.10.	16.10.	10.10.	16.10.

2.1.2 Samplings and measurements

Volumetric soil moisture content was measured with TDR probes (TRIME-EZ, IMKO GmbH, Ettlingen, D; rod length 16 cm). Immediately after sowing date 2, probes were implemented in one F2 and one R2 plot per environment. Plots were selected as representative for each environment. Sensors were positioned within the sugar beet rows and covered 0-16 cm soil depth. In R2 treatments, the probes were placed on top of the ridges. Three probes per treatment were used as internal replicates. Daily mean values were calculated from hourly records memorised on a DL2e Data Logger (Delta-T Devices Ltd., Cambridge, UK) during the growing season. In addition, rainfall was determined 1 m above ground in each environment.

Soil temperature was measured in the same plots as soil moisture by using Pt 100 probes. Sensors were installed shortly after sowing date 2 in 3-5 cm soil depth with four internal replicates per plot. Readings were made every 10 minutes, from which daily means were computed. In each cultivation technique, soil temperature measured on one plot of sowing date 2 was considered to represent the temperature on sowing date 1. Data of air temperature in 2 m above ground were provided by the meteorological station Stöcken near Uelzen.

Soil penetration resistance (PR) was measured several weeks after sowing when the soil had widely resettled after tillage and ridge forming (Tab. 1). The penetrologger (Eijkelkamp, Giesbeek, NL) was equipped with a cone having a cross-sectional area of 1 cm^2 and an angle of 60°. In all plots, measurements were performed in-row with ten internal replicates per plot. According to the ridge height, mean values for the soil depth 0-15 cm and 16-30 cm were calculated.

Undisturbed soil core samples were taken vertically from the soil depth 5-10 cm with six internal replicates per depth from all plots, to determine air capacity of the soil (pore volume > 50 µm equivalent diameter). A detailed description of the procedure is given by *Heuer* et al. (2006).

The dimensions of the ridges were determined after the soil had resettled by measuring ridge height above ground, width at the ground and the top, and length of the legs with five replicates per plot. The size of the soil surface area was calculated from this data and is given relative to 1 m^2 of soil surface in flat cultivation treatment.

Number of emerged plants was counted daily or every second day in two rows per plot (10 m long each) during the period of field emergence (Tab. 1). Absolute field emergence was calculated from the number of emerged plants divided by the number of seeds, which was deduced from the average in-row seed distance. Plot effects on the absolute field emergence were levelled by calculating the relative field emergence: for each plot the absolute field emergence of day n was related to the final absolute field emergence. The date of 50 % relative field emergence was calculated by linear interpolation between two adjacent data points. The number of days between sowing and 50 % relative field emergence was calculated and is given as a measure for the pace of field emergence.

During the growing season, three manual harvests were performed. The first harvest was conducted at the 4-6-leaf-stage (mid May-early June), the second harvest was at canopy closure in June and the third harvest in August. From each plot, an acreage of 5 m² was harvested. The final harvest was performed in mid October on 10 m² per plot with a one-row plot harvester (Tab. 1). At harvest at the 4-6-leaf-stage, plants were not fractionated, at all further harvests leaves (petioles + leaf blades) including tops, and beets were recorded separately. Beets and leaves were separated directly underneath the green leaves. The number of harvested plants was counted and leaf fresh matter was weighed in the field. At the harvests at 4-6-leaf-stage and canopy closure, all harvested leaves and beets were carried to the lab, where they were washed (beets only) and macerated. Sub-samples were weighed, oven-dried at 105°C and weighed again. Data were used for calculation of total plant dry matter yield (leaf + beet, DMY).

Beets from the August and October harvests were washed in the tare house, weighed and processed to brei. After storage of brei samples at -18°C, technical quality parameters were determined with an automatic beet brei analyser (Venema, Groningen, NL). The sugar content (SC) was determined polarimetrically (ICUMSA, 1994), the amount of Na and K was analysed flame photometrically, the α-amino-N-content (AmN) was measured fluorometrically with the OPT-method (*Burba* and *Georgi*, 1975/76). Root yield (fresh weight, RY) and white sugar yield (WSY) were calculated according to *Märländer* et al. (2003) and are given for the ridge treatment relative to flat cultivation technique (October harvest only). At October harvest, the portion of fangy and forked beets was rated as a parameter for mechanical stress encountered by the plants.

2.2 On-farm experiments

The influence of ridge compared to flat cultivation on sugar beet yield was tested under large-scale field conditions in 35 on-farm experiments (environments) located in the Uelzen region. Comparisons were conducted at 20 loessial sites and 15 sandy sites in 2005-2007.

In each environment, sugar beet was cultivated with ridge and flat cultivation technique on immediately adjacent and homogenous sub-fields without replication. Usually, cereal crops preceded sugar beet. After stubble breaking with a rigid tine cultivator, mostly mustard or fodder radish was grown as a catch crop. If necessary, above ground catch crop material was mulched. Ridge forming and sowing were accomplished with the same six-row ridge former and attached sowing machine as used for the field experiments described earlier. Prior to ridge forming, no spring-tillage was performed for seedbed preparation. Flat cultivation treatment usually was shallowly tilled and sown with conventional sowing machines available on the farm.

Fertilisation and pest control were conducted according to approved regional standards. Management was uniform in both cultivation techniques. In mid September, an acreage of 10 m² was hand-harvested with four replicates. Beet fresh weight was determined in the tare house. Subsequently, beets were processed to brei for analysis of technical quality as described above. Relative means for RY, SC, AmN and WSY in ridge cultivation treatment (flat = 100) were calculated for sandy and loessial sites separately.

2.3 Statistical analysis

Software packet SAS, Version 9.1 (SAS Institute Inc., Cary, USA) was used for statistical analysis of the plot experiments. Normal distribution of data residues was tested (Shapiro-Wilk-test, $p \leq 0.1$) with the UNIVARIATE procedure *(Dufner* et al., 2002*)*. For parameters measured with internal replicates, mean values were calculated for each plot as arithmetic means and used for further analyses. The ANOVA was performed with the MIXED procedure setting cultivation technique and sowing date as fixed effects and environment (site x year; *Wolf* and *Märländer*, 1994) as random effect. Effects were regarded significant at $\alpha \leq 0.05$ (*F*-Test). The LS MEANS procedure was applied to calculate mean values. In case of significant *F*-values, Tukey's test was used at $\alpha \leq 0.05$ for comparison of individual treatment means.

Effects of cultivation technique and sowing date on sugar beet growth in Suderburg 2006 and 2007 were very similar and therefore analysed together. In contrast, effects in Natendorf 2006 and Natendorf 2007 were different from the other environments. Thus, statistical analysis was conducted separately for these environments. Treatment values of PR and fanginess varied considerably between sites differing in soil type but were very similar at the same soil types. Therefore, means across years were calculated separately for Suderburg (sand) and Natendorf (loess).

Software packet SIGMA PLOT, Version 10.0. (Systat, San Jose, USA) was used for graphical presentation.

Standard deviation was calculated from the data of the on-farm experiments and is given in the figures.

3 Results

3.1 Plot experiments

The influence of cultivation technique on soil temperature and volumetric water content was similar in all environments. Therefore, results from Suderburg 2006 are presented as representative for all environments (Fig. 1). Mean daily soil temperature in 3-5 cm depth was about 2 °C when the measurements started in the first decade of April and rose up to 16 °C by mid May (Fig. 1, A). In the ridge cultivation treatment, temperature was up to 1.4 °C higher compared to flat cultivation, with the exception of periods characterised by declining temperatures resulting in equal values in both cultivation technique treatments. In general, soil temperature in 3-5 cm depth was closely linked to air temperature.

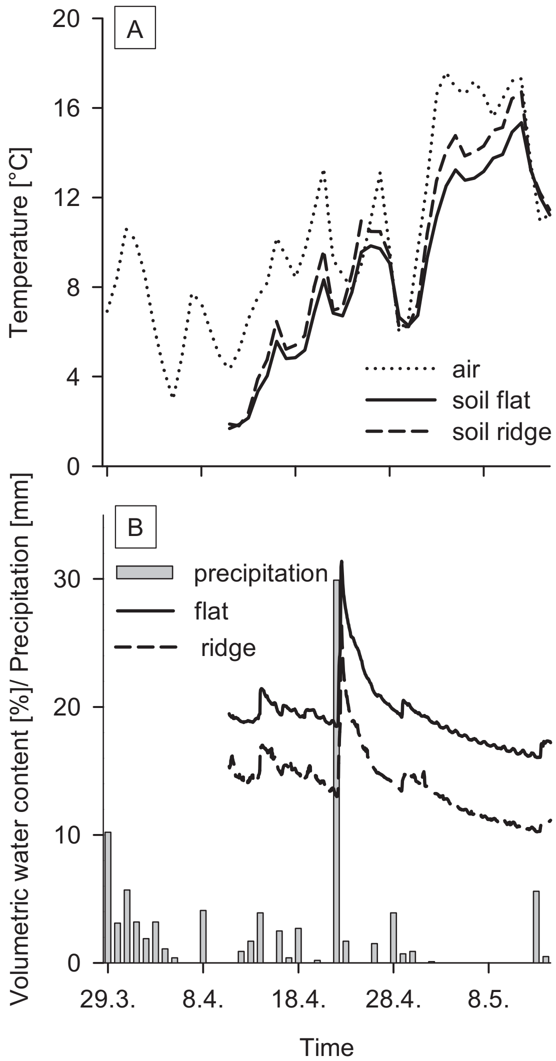

Fig. 1: Effect of flat and ridge cultivation on soil temperature (3-5 cm depth, A) and volumetric water content (0-16 cm depth, B) in the period between sowing and harvest at 4-6-leaf-stage. Additionally, air temperature (2 m above ground) and precipitation (1 m above ground) are shown, Suderburg 2006.

In Suderburg 2006, water content in 0-15 cm soil depth varied during sowing and harvest at the 4-6-leaf-stage between 10-30 m^3 100 m^{-3} (Fig. 1, A). Similar results were obtained in Suderburg 2007 (sandy soil), whereas higher values up to 40 m^3 100 m^{-3} were measured in Natendorf 2006 and 2007 (loessial soil, not shown) due to differences in soil texture. The course of the soil water content closely followed time and amount of rainfall. In all environments, the volumetric water content in the ridge cultivation treatment was 4.2-5.4 m^3 100 m^{-3} below values obtained with flat cultivation technique.

The influence of cultivation technique and sowing date on soil structure was examined by PR and air capacity measurements. Generally, PR values from 0-15 cm depth were below 1 MPa while data from 16-30 cm depth exceeded 1 MPa up to 2.7 MPa at maximum. At the loessial site (Natendorf), PR values were mostly lower than at the sandy site (Suderburg). In Suderburg, PR was substantially lower in ridge compared to flat cultivation in both 0-15 cm (ridge height) and 16-30 cm soil depth. Moreover, PR values were significantly higher at sowing date 1 compared to sowing date 2 (Fig. 2). In Natendorf, 0-15 cm depth, flat cultivation at sowing date 1 caused the highest PR, whereas values from sowing date 2 and ridge cultivation (both sowing dates) were significantly lower and differed only slightly. In 16-30 cm soil depth, PR increased after flat compared to ridge cultivation, and sowing date 1 caused higher values than sowing date 2 (Fig. 2).

Air capacity in 5-10 cm soil depth was about 5 m^3 m^{-3} higher in ridge compared to flat cultivation (not presented). Ridge forming increased soil surface area about 40 % in ridge compared to flat cultivation (not presented).

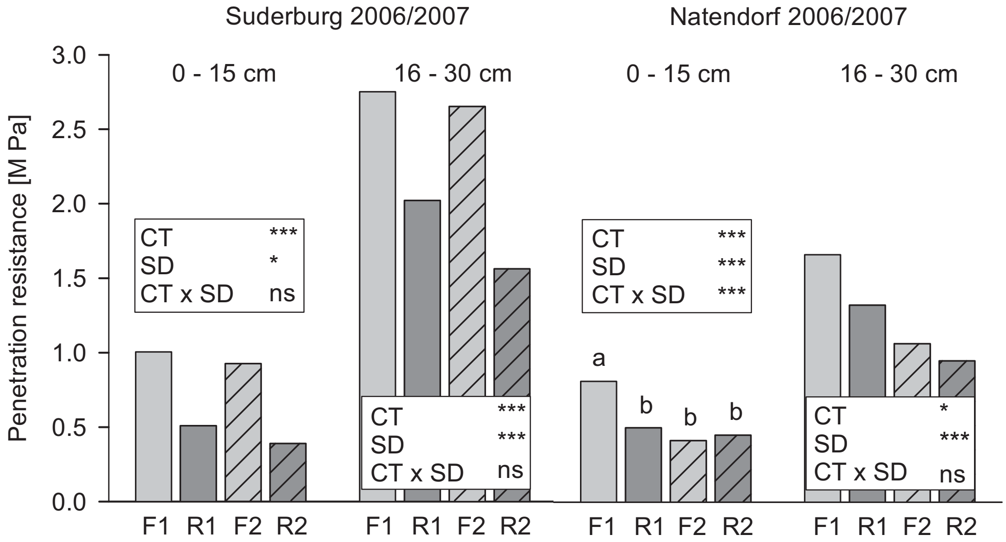

Fig. 2: Influence of cultivation technique (CT; F = flat, R = ridge) and sowing date (SD; 1, 2 = SD 1, 2) on the penetration resistance of the soil in 0-15 cm and 16-30 cm depth; mean of Suderburg 2006 and 2007, and Natendorf 2006 and 2007; probability of *F*-values α ≤ 0.001 (***), 0.01 (**), 0.05 (*), ns = not significant; different letters within one column group indicate significant differences (Tukey, α ≤ 0.05).

The pace of field emergence was depicted by the number of days between sowing and 50 % relative field emergence (Fig. 3). In Suderburg 2006/2007 and Natendorf 2007, field emergence was significantly accelerated by ridge compared to flat cultivation as well as by sowing date 2 compared to sowing date 1. At Suderburg 2006/2007 e.g., 50 % relative field emergence occurred at days 16.5 (R2) and 19 (F2) in sowing date 2 treatment, whereas after sowing date 1 24.5 (R1) and 27 (F1) days were required. Although 50 % relative field emergence occurred after a larger number of days in sowing date 1 compared to sowing date 2, plants emerged at an earlier date the earlier seeds were sown (Fig. 4). Time lag was 2-5 days.

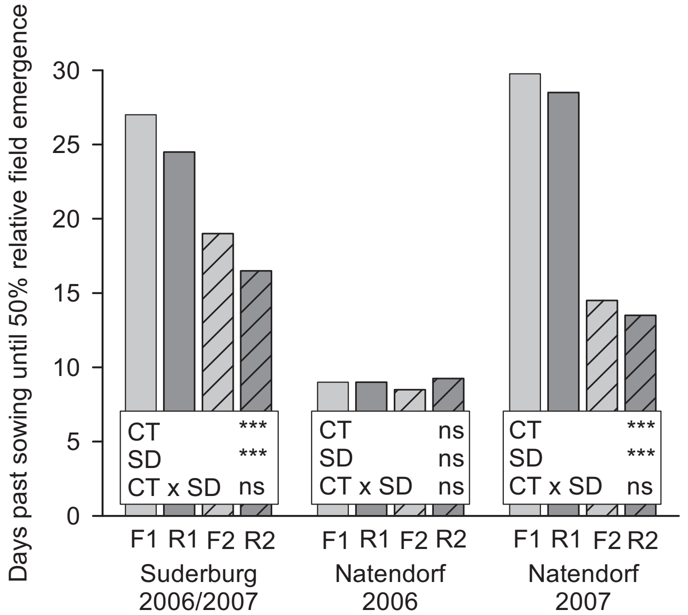

Fig. 3: Influence of cultivation technique (CT; F = flat, R = ridge) and sowing date (SD; 1, 2 = SD 1, 2) on the number of days past sowing until 50 % relative field emergence; mean of Suderburg 2006/2007, Natendorf 2006 and Natendorf 2007; probability of *F*-values α ≤ 0.001 (***), 0.01 (**), 0.05 (*), ns = not significant.

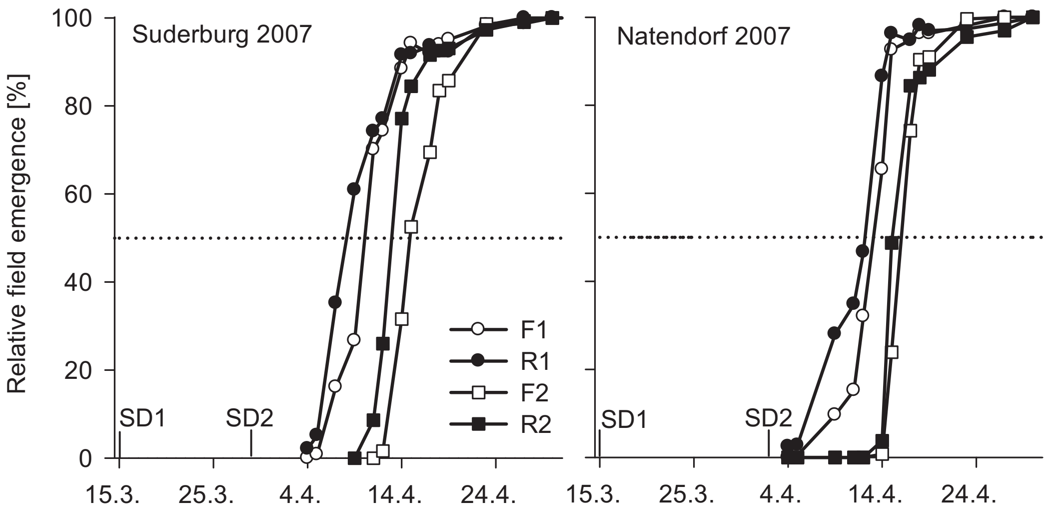

Fig. 4: Effect of cultivation technique (F = flat, R = ridge) and sowing date (SD, 1, 2 = SD 1, 2) on relative field emergence in Suderburg 2007 and Natendorf 2007.

In Natendorf 2007, the difference in number of days for 50 % relative field emergence between sowing dates was larger than in Suderburg 2006/2007. In Natendorf 2006, neither cultivation technique nor sowing date affected pace of field emergence. Moreover, the number of days required for 50 % relative field emergence was 8 to 9.25 days only, which is considerably lower compared to Natendorf 2007 and Suderburg 2006/2007 (Fig. 3).

At harvest at the 4-6-leaf-stage (mid May-early June), DMY in Suderburg 2006/2007 was significantly increased by ridge compared to flat cultivation, and by sowing date 1 compared to 2 (Fig. 5 A, Tab. 2). In Natendorf 2006, yield level was substantially lower than in the other environments. Moreover, treatment effects were small and insignificant except for sowing date (SD1 > SD2; Fig. 5 A, Tab. 2). In Natendorf 2007, a significant interaction between cultivation technique and sowing date occurred. Yield measured in ridge cultivation treatment at sowing date 1 was higher compared to the other treatments (Fig. 5 A, Tab. 2).

At canopy closure (end of June), DMY was significantly higher in ridge compared to flat cultivation in Suderburg 2006/2007 and Natendorf 2007 (Fig. 5 B, Tab. 2). However, yield increase due to early sowing only occurred in Suderburg 2006/2007. In Natendorf 2006, neither cultivation technique nor sowing date affected DMY at canopy closure.

In August, ridge cultivation significantly increased RY in Suderburg 2006/2007 while sowing date had no effect. In Natendorf 2006 and Natendorf 2007, neither cultivation technique nor sowing date significantly influenced RY (Fig. 5 C, Tab. 2). At final harvest in October, RY was significantly higher in ridge compared to flat cultivation in Suderburg 2006/2007 and Natendorf 2007. Sowing date had no influence. In Natendorf 2006, the *F*-Test indicated a significant interaction between cultivation technique and sowing date, which was not confirmed by the more detailed least square means comparison (Fig. 5 D, Tab. 2).

Data from the October harvest were used to calculate the mean relative effect of ridge compared to flat cultivation (= 100) on yield and relevant technical quality parameters irrespective of sowing date. Increase in RY due to ridge cultivation was 7.1 % in Suderburg 2006/2007 and 8.4 % in Natendorf 2007 (Fig. 6). In Natendorf 2006, cultivation technique had no clear influence on RY. In all environments, SC was affected only slightly with values ranging from 98.4 % to 101.1 %. AmN was increased by ridge cultivation in all environments except Natendorf 2007. Effects of cultivation technique on WSY closely followed those on RY accounting for 8.3, 9.5 and -2.2 % in Suderburg 2006/2007, Natendorf 2007 and Natendorf 2006, respectively.

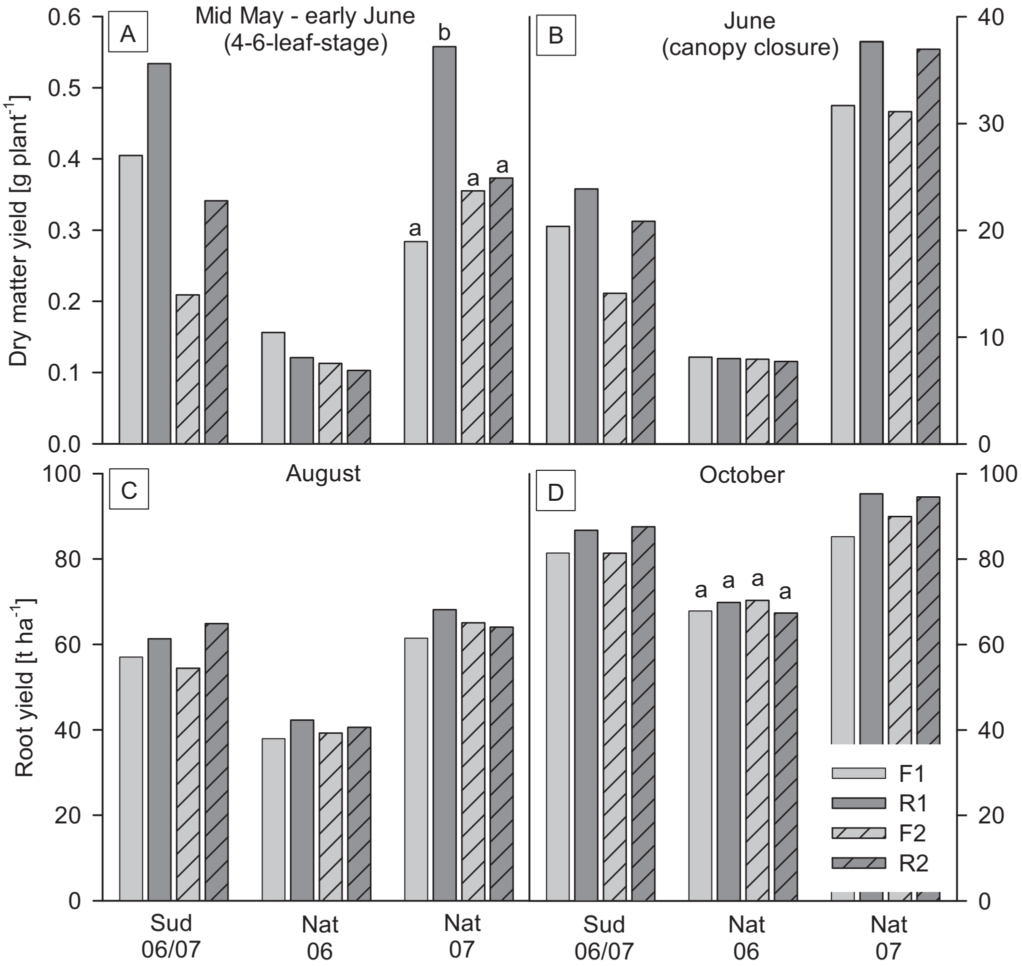

Fig. 5: Influence of cultivation technique (CT; F = flat, R = ridge) and sowing date (SD; 1, 2 = SD 1, 2) on dry matter yield per plant at harvest in mid May-early June (4-6-leaf-stage; A) and June (canopy closure; B), and on root yield in August (C) and October (D); means for Suderburg 2006/2007 (Sud06/07), Natendorf 2006 (Nat06), Natendorf 2007 (Nat07); different letters within one group of columns indicate significant interactions between CT and SD (Tukey, α ≤ 0.05).

Tab. 2: Probability level of *F*-values α ≤ 0.05 for the influence of cultivation technique (CT) and sowing date (SD) on dry matter yield (DMY) per plant at harvest at 4-6-leaf-stage and row closure, root yield in August and October for Suderburg 2006/2007 (Sud06/07), Natendorf 2006 (Nat06), Natendorf 2007 (Nat07); ns = not significant.

		CT	SD	CT x SD
DMY 4-6-leaf-stage	Sud06/07	0.001	0.008	ns
	Nat06	ns	0.036	ns
	Nat07	0.002	ns	0.004
DMY canopy closure	Sud06/07	<0.001	0.003	ns
	Nat06	ns	ns	ns
	Nat07	0.001	ns	ns
RY August	Sud06/07	0.001	ns	ns
	Nat06	ns	ns	ns
	Nat07	ns	ns	ns
RY October	Sud06/07	0.017	ns	ns
	Nat06	ns	ns	0.002
	Nat07	0.007	ns	ns

Fanginess of sugar beet storage roots harvested in October was strongly influenced by site whereas variation between years was only small. Therefore, analysis was performed separately for Suderburg (sandy soil) and Natendorf (loessial soil). In Natendorf, percentage of fangy beets did not significantly differ between cultivation techniques and sowing dates. Contrastingly, in Suderburg the difference between cultivation techniques was large and significant: the percentage of fangy beet storage roots was considerably higher after flat (25.4 %) compared to ridge cultivation (4.5 %). Sowing date effects were only small and insignificant (Tab. 3).

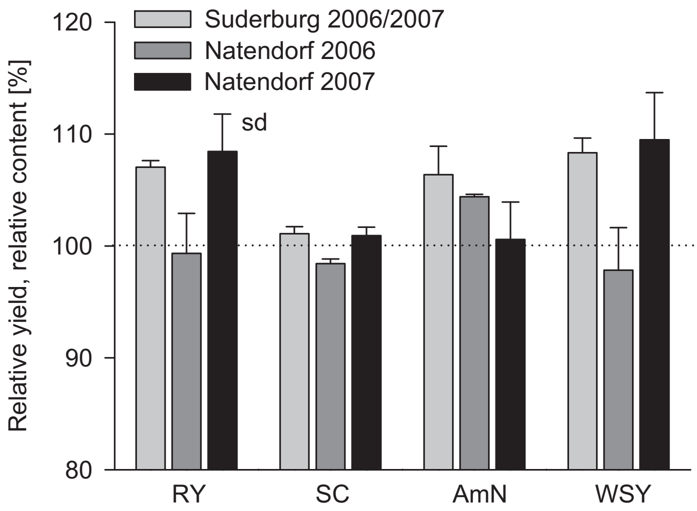

Fig. 6: Effect of ridge cultivation relative to flat cultivation (= 100) on root yield (RY), sugar content (SC), amino-N-content (AmN) and white sugar yield (WSY) at final harvest in October; sd = standard deviation.

Tab. 3: Influence of cultivation technique (F = flat, R = ridge) and sowing date (SD; 1, 2 = SD 1, 2) on fanginess of sugar beet storage roots (%) at final harvest in October; mean of 2006 and 2007; different letters within one site indicate significant differences between cultivation techniques (*F*-Test, $\alpha \leq 0.05$).

Site	F1	F2	Mean F	R1	R2	Mean R
Suderburg (sand)	27.5	23.2	25.4 A	4.7	4.2	4.5 B
Natendorf (loess)	7.8	7.4	7.6 a	7.0	6.8	6.9 a

3.2 On-farm experiments

Data from the on-farm experiments were used to elucidate the importance of soil texture for the impact of ridge cultivation on sugar beet yield (Fig. 7). Ridge cultivation increased RY by about 7.0 % on sandy sites and by 8.5 % on loessial sites compared to flat cultivation (= 100). SC and AmN remained widely unaffected by cultivation technique, but standard deviation was high for AmN. WSY closely followed RY: it was increased by ridge compared to flat cultivation (sandy sites: 7.3 %; loessial sites: 8.9 %).

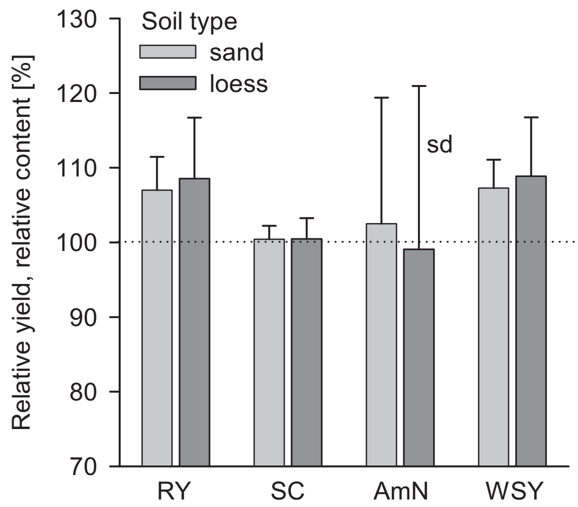

Fig. 7: Effect of ridge compared to flat cultivation (= 100) on root yield (RY), sugar content (SC), amino-N-content (AmN) and white sugar yield (WSY); means of 15 sandy and 20 loessial sites in the Uelzen region 2005-2007; sd = standard deviation.

4 Discussion

4.1 Effect of cultivation technique on soil temperature and soil moisture

Usually, prior to sowing of agricultural crops the soil is (mechanically) tilled to generate a soil structure favourable for plant growth (*Diepenbrock* et al., 2005). During tillage operations, spatial distribution and volumetric portion of water, air and soil particles are modified influencing thermal properties of the bulk soil (*Lexander*, 1993; *Usowicz* et al., 1996). In the present plot experiments, the soil was loosened about 14 cm deep, mixed and compressed immediately before sowing in both cultivation techniques included. Additionally, in ridge cultivation the soil was intensively tilled with a rotor and formed to ridges. Thereby soil surface increased by about 40 % and pore volume in ridge plots increased by about 5 m^3 m^{-3}. Air located in the pores has much less heat capacity than water (*Guérif* et al., 2001). Probably, the enlarged soil surface in ridge cultivation and the more favourable angle of incidence for sunrays at ridge legs increased radiation absorption. Likewise, heat transport to the soil by convection of warm atmospheric air might have been enhanced by the increased soil surface area. Finally, the named factors may have contributed to diminish water content by about 5 $m^3\ m^{-3}$ in ridge compared to flat soil and to increase mean daily soil temperature by up to 1.4 °C during field emergence. Our results confirm effects on water and heat balance of ridges as described by *Benjamin* et al. (1990). In their study on the ideal height of ridges, the authors determined a higher temperature and faster soil desiccation in ridge compared to ridge furrow and flat soil over a variety of ridges differing in height.

4.2 Field emergence and early plant growth

If water and oxygen supply are non limiting, increasing soil temperature is known to stimulate pace and rate of sugar beet field emergence under European spring temperature conditions (*Scott* et al., 1973; *Gummerson*, 1986). *Durr* and *Boiffin* (1995) examined germination under controlled conditions and found 50 % germinated sugar beet seeds at 20 °C after 1.8 days, whereas at 10 °C 4.6 days were needed. Consistently, *Campbell* and *Enz* (1991) measured 50 % field emergence after 7-8, 12 and >14 days after sowing at 25, 17 and <14 °C, respectively.

For the environments included in our plot experiments, soil temperature data are not available for the whole field emergence period. Therefore, air temperature has to be taken for characterisation of the environment specific temperature level. Mean air temperature for the period between sowing to 50 % relative field emergence was about 7.1-10.8 °C in Suderburg 2006/2007 and Natendorf 2007 (mid March to mid April). A considerably higher temperature level of 15.3-16.5 °C after sowing occurred in Natendorf 2006 (beginning of May). Consistently, the number of days until 50 % relative field emergence was higher in Suderburg 2006/2007 and Natendorf 2007 compared to Natendorf 2006, even if variation due to treatment effects within single environments was large. In Suderburg 2006/2007 and Natendorf 2007, 50 % relative field emergence occurred about 1-3 days earlier in ridge compared to flat cultivation treatments because mean daily soil temperature in the seed layer averaged about 0.8 °C higher. In Natendorf 2006, the temperature difference due to cultivation treatment was still about 0.5 °C. However, pace of field emergence was not significantly different. Apparently, the growth enhancing effect of temperature increase by ridge cultivation was strongly influenced by the absolute soil temperature level during germination and field emergence.

This is confirmed by *Ehlers* (1980), who emphasised the importance of the plant specific minimal and optimal temperature for germination processes. Within the plant specific minimal and optimal temperature range, the time required for germination bisects when temperature doubles. The closer a temperature to the optimal temperature, the faster growth processes take place and the smaller stimulating effects of an additional temperature increase are. According to *Milford* et al. (1985), the base temperature for sugar beet growth is 3 °C, the optimal temperature is above 20 °C. *Terry* (1968) determined temperatures of 17-24 °C as optimal for sugar beet growth. Obviously, temperature level was close to the optimum after late sowing in May in Natendorf 2006 and thus, temperature increase due to ridge cultivation did not enhance field emergence compared to flat treatment: conditions for emergence and growth were favourable in both cultivation techniques.

In Suderburg 2006/2007, results of the harvest at the 4-6-leaf-stage directly reflect differences in the absolute date of field emergence between cultivation technique and sowing date treatments: ridge cultivation and early sowing resulted in an earlier field emergence date and higher DMY, while field emergence was at a later date in flat cultivation and sowing date 2 treatments and thus, the later treatments yielded less. In average of both sowing dates, ridge cultivation increased yield by about 45 % compared to flat cultivation. Similarly, *Stibbe* and *Märländer* (2002) reported on the beneficial effect of early field emergence on plant DMY at early harvest dates. Early sowing is known to improve early leaf development in spring and to promote light interception as a basis for high yields (*Scott* et al., 1973; *Märländer*, 1991).

Moreover, increasing temperature in the rooting zone from 10 to 20 °C was shown to enhance early plant growth of sugar beet independent of air temperature level *(Hoffmann*, 1993; *Hoffmann* and *Buhse*, 1996). For our study (Suderburg 2006/2007, Natendorf 2007), it is therefore to conclude that the higher temperature in ridge compared to flat soil has not only accelerated germination and field emergence but also enhanced subsequent growth until 4-6-leaf-stage.

In addition, differences in soil structure due to cultivation technique may influence early root and shoot growth. As a parameter of soil mechanical strength, PR provides information on the ability of fibrous roots to penetrate the soil (*Taylor* et al., 1966; *Harrach* and *Vorderbrügge*, 1991; *Helal* et al., 1994) and furthermore, the impedance the plant has to overcome during taproot formation (*De Leenheer* and *Appelmans*, 1973). PR increases with decreasing soil water content and increasing dry bulk density, and is higher on sandy soil, which is often more compact than loessial soil (*Petelkau* et al., 1999). According to *Locher* and *De Bakker* (1990), unimpeded fibrous root growth requires values below 1.5 MPa, and above 3 MPa soil penetration by roots is completely stopped. The uppermost 30 cm soil horizon is explored by sugar beet roots during the first 3 weeks after emergence (*Garz* et al., 1992) and thus particularly influences early growth and yield at the 4-6-leaf-stage. In our study, the 0-15 cm soil layer represents the height of the ridges.

In Suderburg 2006/2007, DMY at the 4-6-leaf-stage differed between cultivation techniques reverse to PR in 0-15 cm and 16-30 cm soil depth. Presumably, low PR in ridge compared to flat cultivation treatment contributed to the observed yield increase. In 0-15 cm soil depth, PR was generally low with values ≤1 MPa and thus, effects on early fibrous root growth were unlikely, although PR may increase rapidly due to soil desiccation. In 16-30 cm soil depth, absolute PR level was substantially higher than in the layer above and cultivation treatment effects were more pronounced. However, data on rooting intensity or plant nutrient concentration (*Tomanová* et al., 2006), which could provide more detailed information on the effects of measured PR differences on crop growth were not determined. Moreover, higher soil moisture at sowing date 1 compared to sowing date 2 caused higher PR, which in turn may have limited the yield increasing effect of earlier sowing. Unfortunately, our data can not contribute to clarify this open question.

In many studies, yield of arable crops was strongly affected by the interaction of site x year (environment). E.g., data from national sugar beet variety performance trials revealed a variance for the environment of 53 % of the total variance for WSY in autumn (*Wolf* and *Märländer*, 1994). In long-term field trials reported by *Glattkowski* and *Märländer* (1994), the variance for the interaction of site x year accounted for 26 % for the parameter RY at harvest. In our study, yield at the 4-6-leaf-stage in Natendorf 2006 and Natendorf 2007 considerably differed from effects previously discussed for Suderburg 2006/2007. In Natendorf 2006, DMY at the 4-6-leaf-stage did not differ between cultivation techniques: as already discussed, elevated temperature level caused rapid and almost simultaneous field emergence in all treatments, resulting in uniform plant growth and equal yield.

At the loessial soil in Natendorf 2007, early growth of sowing date 1 sugar beet plants can be assumed as considerably impaired by a crusted soil surface. Crusts are known to arise from rainfall and following soil desiccation shortly after sowing, thereby hampering field emergence and further plant growth (*Kooistra*, 1989; *Duval* and *Boiffin*, 1990; *Guérif* et al., 2001). Such conditions were clearly identified in Natendorf 2007. Limited oxygen diffusion through the crusted soil layer may have compromised germination and early growth (*Ehlers*, 1980). Furthermore, seedling vitality might have decreased by reduced water availability during subsequent dry periods (*Aura*, 1975). Especially in flat cultivation, sugar beet seedlings were interfered when breaking through the soil surface, thereby causing a several days lasting stagnation of field emergence especially in treatment flat cultivation/sowing date 1. In addition, numerous seedlings were distorted corkscrew-like. In ridge contrary to flat cultivation, plant emergence proceeded more steadily. However, number of days until 50 % relative field emergence was only slightly increased in flat compared to ridge cultivation treatment. But soil crusting in treatment flat cultivation/sowing date 1 probably decreased yield at 4-6-leaf-stage considerably: DMY in ridge cultivation was almost twice as high as with flat tillage. In Suderburg 2006/2007, revealing similar effects of cultivation technique on the number of days past sowing until 50 % field emergence, yield differences at 4-6-leaf-stage were only half of those detected in Natendorf 2007. Here, field emergence started about 3 days earlier in ridge compared to flat cultivation due to higher soil temperature. Consequently, seedlings in ridge cultivation plots were further developed and stronger with increasing crust formation. Under such conditions, soil crusting could obviously less hamper plant growth.

4.3 Yield from canopy closure until final harvest including technical quality

Yield effects detected in Suderburg 2006/2007 and Natendorf 2007 were very similar, and therefore are simultaneously discussed in the following. At canopy closure in June, relative DMY increase in ridge compared to flat cultivation was about 25 %. In August, RY was about 9.0 % higher in ridge compared to flat cultivation. At final harvest in October, ridge compared to flat cultivation of sugar beet still increased RY by about 7.8 % (cf *Schlinker* et al., 2007). Conclusively, the relative yield effect of ridge cultivation was highest at the beginning of the growing season and diminished with proceeding plant growth during summer. Intra-specific competition for light in the crop during major plant growth in summer could account for this (*Röver*, 1995).

In Natendorf 2006, no yield difference between ridge and flat cultivation was detected during the entire growing season. Average yield was 69 t ha^{-1} RY and thus considerably lower compared to Suderburg 2006/2007 (84 t ha^{-1}) and Natendorf 2007 (91 t ha^{-1}). In addition to delayed sowing at the beginning of May, low rainfall during summer assumedly contributed to the low yield level in Natendorf 2006: from June to August 2006 only 140 mm of rainfall were measured. In the same period in Suderburg 2006, rainfall was 370 mm, whereof 135 mm was supplied by irrigation. *Kenter* (2003) elucidated the limitation of yield formation due to inadequate water supply in a series of field trials with and without irrigation.

Technical quality of sugar beets differed just slightly between cultivation techniques in all environments. Effect of cultivation technique on SC was generally small. Increased AmN in ridge compared to flat cultivation might have been caused by enhanced N mineralisation due to higher soil temperature *(Kladivko* and *Keeney*, 1987; *Van Schöll* et al., 1997). Furthermore, N mineralisation rate is increased by intensive tillage operations (*Hassink*, 1992; *Silgram* and *Shepherd*, 1999). Soil loosening with a rotor in ridge treatments of our study was more intensive compared to flat cultivation and thus could have stimulated N mineralisation in ridge cultivation treatments.

Soil structural effects impairing secondary thickening of the taproot can be detected by root shape evaluation scoring thickening of lateral roots and portion of fangy beets (*Gliemeroth*, 1953). *Koch* (2002) reported on the indicator value of root fanginess for soil structure degradation and an increase of fanginess with decreasing tillage intensity. Presented data showed a large difference in fanginess at October harvest between the sandy site Suderburg and the loessial site Natendorf: sandy soils naturally have a larger amount of coarse pores and tend to increased strength. In Suderburg, the significance of soil strength is additionally emphasised by the substantially higher portion of fangy beet in flat compared to ridge cultivation treatment. As previously discussed, this effect might be caused by the lower PR in ridge than in flat treatment at an overall high PR level in 16-30 cm soil depth. Considerably lower PR values in Natendorf caused only little fanginess at October harvest without differences between treatments. Likewise, differences in soil moisture at sowing remained without effect on beet fanginess.

4.4 Influence of cultivation technique on yield and quality of sugar beet as affected by soil type

Sandy soils may substantially differ from loessial soils in their reaction to different tillage techniques. This can affect growth and yield of sugar beet (*Frede* et al., 1994). In order to determine interactions between soil type and cultivation technique, plot and on-farm trials were conducted on both sandy and loessial sites. The data obtained should provide information on the site specific suitability for ridge cultivation of sugar beet as the basis of recommendations to farmers.

On average of all sandy sites included in our study, yield increase due to ridge cultivation was about 7.0 % for RY and WSY. Similarly, across the loessial sites yield increased by 8.5 %. Overall influence of cultivation technique on yield detected in the plot experiments Suderburg 2006/2007 and Natendorf 2007 corresponded well with yield and quality results obtained from the on-farm trials.

Results from on-farm trials conducted under conditions differing in climate and soil characteristics have recently been reported by *Schlinker* et al. (2007). In East Westphalia yield increase caused by ridge cultivation was detected during a three years study and averaged 7.8 %, whereas in Uelzen-Holstein yield increase was 6.9 % on average. However, in the Rhineland WSY was lower in ridge compared to flat cultivation in two out of three years. *Schlinker* et al. (2007) supposed the warmer spring climate in the Rhineland compared to the cooler regions of East Westphalia and Uelzen-Holstein to be the cause for this lack of yield increase obtained from ridge cultivation. The explanation is supported by the results from our plot experiments. Similar effects were reported by *Cox* et al. (1990) for maize cultivation on ridges under cool spring temperatures and waterlogged soil conditions.

5 Conclusions and outlook

The present data reveal higher yield for ridge compared to conventional flat cultivation of sugar beet, if soil temperature during field emergence and early growth is substantially increased by ridge forming (0.5-1 °C). The growth enhancing effect of temperature increase can be expected as high, if the base level of soil temperature is below 10 °C. Usually this condition is prevalent in Northern Germany, when sowing takes place in March and the first half of April. In this case, plant growth can be enhanced up to 50 % until 4-6-leaf-stage. Thereof, a yield increase of 5-10 % is preserved until autumn. If the soil temperature is considerably above 10 °C due to year and/or site specific effects, no yield increase caused by ridge cultivation is to be expected. Differences between sandy and loessial soils in the magnitude of yield increase obtained from ridge cultivation do apparently not exist.

Neither in ridge nor in flat cultivation, plant growth was influenced by a hampered soil structure after spring tillage and sowing conducted at very high soil moisture compared to a several days delayed sowing at lower soil moisture level. Although early growth of sugar beet was enhanced by sowing a few days earlier, sowing date did not influence autumn yield. At loessial soil, tillage and sowing at high soil moisture is at risk to cause a sealed and crusted soil surface, impairing field emergence and subsequent plant growth. Thus, a preponed sowing date at very high soil moisture does not give any advantage to ridge cultivation, if the seedlings' water requirement for germination and field emergence is fully met at the site-specific optimal sowing date.

For an overall appraisal of ridge cultivation of sugar beet in Northern Germany, the potential yield increase has to balance the higher costs for the energy-intensive ridge forming and the lower area capacity/efficiency at sowing: presently, 6-row-machinery operating at lower working speed in ridge cultivation has to compete with 12-/18-row-seeders working at higher speed in flat cultivation. Under current conditions, a yield increase of 3-4 t beets ha^{-1} is required to cover the higher costs of ridge cultivation (*Schlinker* et al., 2007). Normally, this value was exceeded in the present experiments. However, decreasing sugar beet returns in future as well as increasing energy costs will likely diminish the competitiveness of ridge cultivation. On the other hand, advancing of machinery and cultivation/process technique of ridge cultivation, e.g. forward ridge forming in autumn, may reduce costs.

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3. Analysis of yield formation in sugar beet under ridge and flat cultivation

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Abstract

Field trials were conducted in 2006 and 2007 at sandy soil in Uelzen county (Lower Saxony, Northern Germany) to examine the influence of soil properties as effected by ridge compared to flat cultivation on sugar beet crop growth over the growing season. Mean daily soil temperature between sowing (mid-March to mid-April) and May (4-6-leaf-stage) was 7.0 and 6.1 °C in the ridge compared to the flat cultivated soil. At May harvest, ridge cultivation increased dry matter yield by 38.7 % related to flat cultivation. Correlation analysis revealed soil temperature as the most important factor effecting early growth. Between May and June (canopy closure), ridge cultivation significantly increased crop growth rate (CGR) as in the period before, but the influence of soil temperature on plant growth diminished and penetration resistance most closely correlated to CGR. At June harvest, yield increase due to ridge cultivation was 29.7 %. During the second half of the growing season no significant differences between cultivation treatments occurred in CGR, but principal yield effects were preserved until final harvest in October, when white sugar yield was increased by 8.4 % in ridge compared to flat cultivation. Conclusively, the basis of higher final yield in ridge cultivation was established during early growth until June, primarily caused by warmer soil and growth stimulating soil structure. For a comprehensive evaluation of ridge cultivation of sugar beet the higher input of energy and machinery as well as the reduced area capacity at ridge forming and sowing have to be considered.

Keywords: soil structure, soil temperature, penetration resistance, air capacity, nutrient supply, early plant growth, yield increase, sandy soil

1. Introduction

Ridge cultivation systems are common all over the world. They are mostly established for erosion control and conservation of water for crop growth (Hulugalle, 1990; Pikul Jr. et al., 2001; Liu et al., 2006). In Germany, potatoes, asparagus and carrots are grown on ridges, whereas ridge cultivation of sugar beet is hardly known.

Tillage operations principally aim to generate a favourable soil structure in terms of water, oxygen, temperature and nutrient supply for best plant growth (Lexander, 1993). Ridge cultivation of sugar beet was shown effective to fulfil the plant's requirements and to increase yield by 5 to 10 % compared to conventional flat cultivation under soil and climatic conditions of Northern Germany (Schlinker et al., 2007).

While studying growth of ridge crops, several parameters encouraging plant growth have been identified. Frequently, enhanced germination and early growth in ridge cultivation was observed. The enlarged soil surface due to ridge forming increases net radiation absorption (Sharratt et al., 1992), and is supposed to influence water and heat balance of ridges. Benjamin et al. (1990) determined higher temperature and faster soil desiccation within ridges compared to ridge furrows and flat cultivated soil. Krause et al. (2008) demonstrated that ridge cultivation increased soil temperature but decreased soil water content and enhanced germination of sugar beet at a soil temperature level below 10 °C. High soil temperature and intensive tillage operations are known to stimulate nitrogen mineralisation and consequently plant growth (Hassink, 1992; Silgram and Shepherd, 1999). However, data on soil nitrogen mineralisation of ridge compared to flat cultivation of sugar beet are not available yet.

Tillage operations modify the spatial distribution and volumetric fraction of water, air and soil particles (Usowicz et al., 1996), and may thereby influence plant root growth and activity. So far, neither rooting intensity nor nutritional status of sugar beet grown on ridges has been determined. Similarly, little is known during which periods later in the growing season yield formation of sugar beet cultivated on ridges is effected and what are the specific causes for the yield increase observed. Such parameters may alter during the growing season as plant requirements change from germination to leaf and beet growth, and sucrose accumulation in the taproot.

From agricultural practice it is sometimes reported, that water supply of seeds for swelling and germination (Akeson et al., 1980) can be adversely affected by ridge cultivation, thereby endangering crop establishment and yield formation (Schlinker et al., 2007). Ridge forming and sowing at high soil moisture may eliminate this threat, but simultaneously may hold the risk of soil compaction within and underneath the seed horizon (Kooistra, 1989; Richard et al., 1999). A damaged soil structure can hamper root growth and activity (Boone and Veen, 1994), and decrease yield (Jaggard, 1977).

Therefore, this study aimed to identify (i) at what particular period of the growing season sugar beet growth in ridge cultivation is enhanced compared to flat cultivation, (ii) which soil properties cause the differences in crop growth between cultivation systems and (iii) how variation of soil moisture during sowing effects yield formation. Knowing the soil parameters that determine plant growth and the time they influence sugar beet growth most could help to understand the yield increasing processes in ridge cultivation and to optimise this cultivation system for sugar beet.

2. Material and methods

Experimental site and layout

In 2006 and 2007 field experiments were established at Suderburg in Uelzen county, Lower Saxony, Germany (53°52‘ N; 10°26‘ E). The soil was a loamy sand (stagnic Cambisol) consisting of 30 g kg^{-1} clay, 160 g kg^{-1} silt and 810 g kg^{-1} sand (WRB, 2006). Long-term mean annual air temperature and precipitation were 8.7 °C and 685 mm, respectively.

Previous to sugar beet, white mustard (*Sinapis alba*) was grown as a catch crop. Above-ground catch crop material was either rolled or mulched before winter. Seedbed preparation for sugar beet was performed with a disc harrow 14 cm deep immediately before sowing (Table 1).

The experimental treatments consisted of flat and ridge cultivation. Flat cultivation was conducted with a conventional sowing machine (18-rows). Ridges were formed with a six-row ridge former with diabolo rolls (Struik BV, Wieringermeer, NL): a rotor loosened and lifted the soil, following metal sheets and rollers formed and compressed the ridges. The sowing machine was attached to the ridge former. Elevation of the ridges was ca. 9 cm higher than the previous soil surface, the height of the ridges was ca. 15 cm. Seed distance was 18 cm, row and ridge width was 50 cm.

Sowing was performed at two dates determined by sensory evaluation of soil moisture by an experienced agronomist. Sowing date 1 was conducted early when the soil was trafficable but too wet for optimal flat cultivation of sugar beet; at sowing date 2 the soil was clearly drier than at sowing date 1 but still moist. The time lag between sowing dates was 8 or 14 days depending on the year (Table1).

Nitrogen fertiliser was applied to achieve a target supply value of 140 kg N ha^{-1} according to the soil mineral nitrogen (N_{min}) method taking into account the N_{min} content (0-90 cm) in early spring and previous crop effects (Mengel*,* 1991; LWK Niedersachsen, 2008). Fertiliser rates were equal for both cultivation treatments and sowing dates, and amounted to 70 and 90 kg N ha^{-1} in 2006 and 2007, respectively. The fertiliser was applied as ammonium nitrate urea solution before sowing date 1. Further field management was conducted uniformly for all treatments following approved regional standards. Irrigation was applied according to plant requirement and soil water supply (2006: 150 mm in five doses of ca. 30 mm each from June to September; 2007: 27 mm once in April).

In both years, a randomised Latin rectangle design with four replicates was established. Plot size was 9 m in width (18 rows) and 12 m in length. Rows and ridges were orientated in north-south direction.

Table 1: Field management and sampling dates during the sugar beet growing seasons 2006 and 2007; FC = field capacity.

	2006	2007
Field management		
Previous crop	Winter rye (*Secale cereale*)	Winter triticale (*Triticosecale*)
Catch crop	White mustard (*Sinapis alba*)	
Seedbed preparation	Disc harrow (14 cm deep)	
Sowing date 1	03/29[a]	03/15
FC [%] in 0-15 cm depth	110	87
Sowing date 2	04/06	03/29
FC [%] in 0-15 cm depth	100	84
Samplings		
Field emergence	04/18-05/04	04/04-30
Soil mineral N	04/20-10/12	04/18-10/17
Penetration resistance	04/20	05/15
FC (%) in 0-15 cm depth	75	85
Soil cores	05/17-18	05/03-04
Harvest May (4-6-leaf-stage)	05/15	05/14
Harvest June (canopy closure)	06/15	06/12
Harvest August	08/15	08/14
Harvest October	10/10	10/16

[a] month/day

Samplings and measurements

The volumetric soil moisture content was measured with TDR probes (TRIME-EZ, IMKO GmbH, Ettlingen, D; rod length 16 cm). Immediately after sowing date 2, probes were implemented in one flat plot of sowing date 2 and one ridge plot of sowing date 2. Plots were selected as representative for the other plots of the respective treatment. Sensors were positioned within the sugar beet rows and covered the soil depth of 0-16 cm. In ridge cultivation, probes were placed on top of the ridges. Three probes were applied per treatment as internal replicates. Daily mean values were calculated from hourly records memorised on a DL2e Data Logger (Delta-T Devices Ltd., Cambridge, GB) during the growing season. In addition, rainfall was determined 1 m above ground.

Soil temperature was measured in the same plots as soil moisture by Pt 100 probes. Sensors were installed shortly after sowing date 2 in 3-5 cm depth with four internal replicates per plot. Readings were made every 10 minutes, from which daily means were computed. Soil temperature measured in the sowing date 2 plot was assumed to represent the temperature in sowing date 1 plots of the same cultivation treatment also. Mean daily soil temperature was used for calculation of thermal time (TT; °C d^{-1}) taking into account 3 °C as base temperature for sugar beet growth (Milford et al., 1985). Adjusted mean daily soil temperatures were summed up for the following periods (Table 1): 50 % relative field emergence and harvest at 4-6-leaf-stage in May (TT_1), harvest in May and harvest at canopy closure in June (TT_2), harvest in June and harvest in August (TT_3), harvest in August and final harvest in October (TT_4). Data of air temperature 2 m above ground were provided by the meteorological station Stöcken near Uelzen.

In all plots, soil penetration resistance (PR) was measured with a penetrologger (Eijkelkamp, Giesbeek, NL), which was equipped with a cone having a cross-sectional area of 1 cm^2 and an angle of 60°. Measurements were performed to a depth of 45 cm within rows with ten internal replicates per plot several weeks after sowing when the soil had widely settled (Table 1). Mean values for the soil layers 0-15 cm (height of the ridge) and 16-30 cm were computed.

From each plot, undisturbed soil core samples (250 cm³ volume, 8 cm diameter) were vertically taken from the soil layers 5-10 cm and 15-20 cm with six internal replicates per depth (Table 1). Additionally, composite samples of disturbed soil were taken from each plot. Air capacity (AC) was determined according to Koch et al. (2008), defined as the difference between total pore volume and the volume of water retained in the core at 6.2 kPa water tension.

At the middle of July, root samples were taken from 0-15 cm, 16-30 cm and 31-45 cm depth in plots of sowing date 2 of both cultivation treatments by hydraulically pushing a drill (45 cm length; 8 cm in diameter) into the ground. Samplings were repeated three times per plot, at both in- and between-rows/ridges positions. Determination of root length density (RLD) followed the procedure described by Heuer et al. (2008).

From April to harvest in October, N_{min} soil samples were taken in intervals of three weeks. Samples were taken in plots of sowing date 1 at in-rows/in-ridges position from 0-30 cm and 30-60 cm depth, with an auger 2 cm in diameter. Composite samples of seven replicates per depth and plot were analysed according to Hoffmann (1997).

During the period of field emergence (Table 1), the number of emerged sugar beet plants was counted daily or every second day in two rows per plot (10 m long each). Absolute field emergence was derived from the ratio of emerged plants to number of seeds placed. Plot effects on the absolute field emergence were levelled by calculating the relative field emergence: for each plot the absolute field emergence of day n was related to the final absolute field emergence. Thereupon, the date of 50 % relative field emergence was derived by linear interpolation between adjacent dates. The number of days between sowing date and 50 % relative field emergence was calculated to indicate the pace of field emergence.

During the growing season manual harvests were performed on an acreage of 5 m² per plot. The first harvest was conducted at the 4-6-leaf-stage in May, the second harvest was at canopy closure in June and the third harvest in August. The final harvest was performed in the middle of October on 10 m² per plot with a one-row plot harvester (Table 1). At harvest in May plants were not fractionated, while at all further harvests leaves (petioles + leaf blades + tops) and beets were recorded separately. Beets and leaves were separated directly underneath the youngest green leaf. The number of harvested plants was counted and leaf fresh matter was weighed in the field. Representative leaf sub-samples were used for determination of dry matter (DM) content by oven-drying to constant weight. Dry matter yield (DMY, kg ha^{-1}) was calculated from fresh matter yield and DM content.

All beets of a plot were washed in the lab, weighed and processed to brei. After storage of representative brei sub-samples at -18 °C, technical quality parameters sugar content (SC), sodium, potassium and α-amino-N-content (AmN) were analysed following Hoffmann

(2006). White sugar yield (WSY) was calculated according to Märländer et al. (2003). Additionally, DM content of brei material was determined and used to derive beet DMY.

Total plant (May harvest) and leaf dry material was ground, and total nitrogen (N), phosphorus (P) and potassium (K) concentration determined as described by Tomanová et al. (2006).

For evaluation of crop growth over time, the absolute crop growth rate (CGR; g DM m^{-2} d^{-1}) was determined according to Hunt (1990). The daily increase of total plant DMY (y; g m^{-2}) between two sampling dates (t; d) was calculated as: $CGR = (y_2 - y_1) / (t_2 - t_1)$. CGR was calculated for the following periods: sowing to 4-6-leaf-stage in May (CGR_1), May to canopy closure in June (CGR_2), June to August (CGR_3) and August to October (CGR_4).

Statistical Analysis

Software package SAS, Version 9.1 (SAS Institute Inc., Cary, USA) was used for statistical analysis. Normal distribution of data residues was tested (Shapiro-Wilk-test, $p \leq 0.1$) with the UNIVARIATE procedure (Dufner et al., 2002). For parameters measured with internal replicates, arithmetic means were calculated for each plot and used for further analyses. Data from different soil layers were analysed separately for each layer. In a first step, data were computed as a two-factorial ANOVA including cultivation treatment, sowing date and their interaction as fixed effects. Results revealed that no interaction between the two experimental factors occurred. Therefore, sowing date was removed from the statistical model, and data were taken as replicates. The ANOVA was performed with the MIXED procedure setting cultivation treatment as fixed effect and year as random effect. The LS MEANS procedure was applied to compare mean values. Effects were regarded significant at $\alpha \leq 0.05$ (*F*-Test).

Spearman's rank correlation (CORR procedure) was applied to determine the relation between CGR with corresponding TT, and soil physical parameters PR and AC. All data were centred for sowing date and year effects, thus data obtained were influenced by cultivation treatment but not by sowing date and year. Software packet SIGMA PLOT, Version 10.0. (Systat Software Inc., San Jose, USA) was used for graphical presentation.

3. Results

The influence of cultivation treatment on soil volumetric water content was similar in both years (not shown). Water content in 0-15 cm depth varied during the study period between 5 and 30 m^3 100 m^{-3}. Water content was ca. 5 m^3 100 m^{-3} higher in flat compared to ridge cultivation throughout the whole growing season.

In general, soil temperature was closely linked to air temperature. Mean daily soil temperature in 3-5 cm depth rose from ca. 2 °C at sowing up to 16 °C by the middle of May in 2006 and from 8.5 °C up to 19 °C in 2007 (Fig. 1). In both years, mean daily soil temperature was up to 1.8 °C higher in ridge compared to flat cultivation except in periods with declining temperatures, when values were equal.

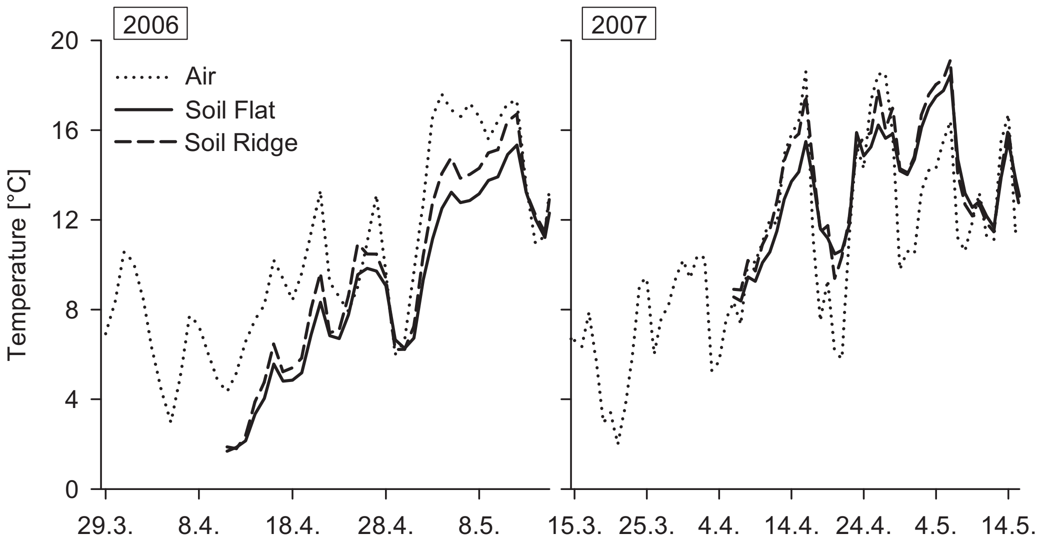

Fig. 1: Course of air temperature (2 m height) and soil temperature (3-5 cm depth) after flat and ridge cultivation of sugar beet between sowing and 4-6-leaf-stage in May; 2006 and 2007.

Mean daily soil temperature was 6.1 °C (flat) and 7.0 °C (ridge) from the beginning of measurements to May harvest, 13.6 °C (flat) and 13.8 °C (ridge) from May to June, 15.3 °C in both cultivation treatments from June to August, and 10.7 °C (flat) and 10.6 °C (ridge) from August to October (mean 2006, 2007; data not shown).

In ridge cultivation, PR constantly was around 0.5 MPa over the 0-15 cm layer (height of ridge), while it gradually increased with depth from 0.5 to 1.5 MPa in flat cultivation (Fig. 2A). On average, PR_{0-15} was significantly higher in flat compared to ridge cultivation (Fig. 2B). In 16-30 cm depth, PR onwardly increased with depth in both treatments; mean PR was significantly lower at ridge compared to flat cultivation. Underneath 30 cm depth, PR increased to a maximum of ca. 5.0 MPa in both cultivation treatments, indicating the plough pan at ca. 30 cm (flat) and 37 cm depth (ridge; Fig. 2A).

In 5-10 cm and 15-20 cm depth, AC was significantly higher at ridge compared to flat cultivation (Fig. 2C), values ranged between 20 and 30 m^3 100 m^{-3}.

At in-rows/in-ridges position, RLD in 0-15 cm depth was 1.3 to 1.5 cm cm^{-3} and revealed no difference between cultivation treatments (Fig. 3). In 16-30 cm and 31-45 cm depth, RLD was significantly lower in flat compared to ridge cultivation. At the between-rows/between-ridges position, no sampling was possible in 0-15 cm depth of ridge cultivation plots, because the furrows of the ridges were free of soil. In flat cultivation, RLD was similar to in-rows/in-ridges position of the same layer. In the 16-30 cm layer, RLD tended to be lower in ridge (1.0 cm cm^{-3}) compared to flat (1.4 cm cm^{-3}) cultivation, while in 31-45 cm RLD in ridge cultivation (1.1 cm cm^{-3}) significantly exceeded values of flat cultivation (0.3 cm cm^{-3}).

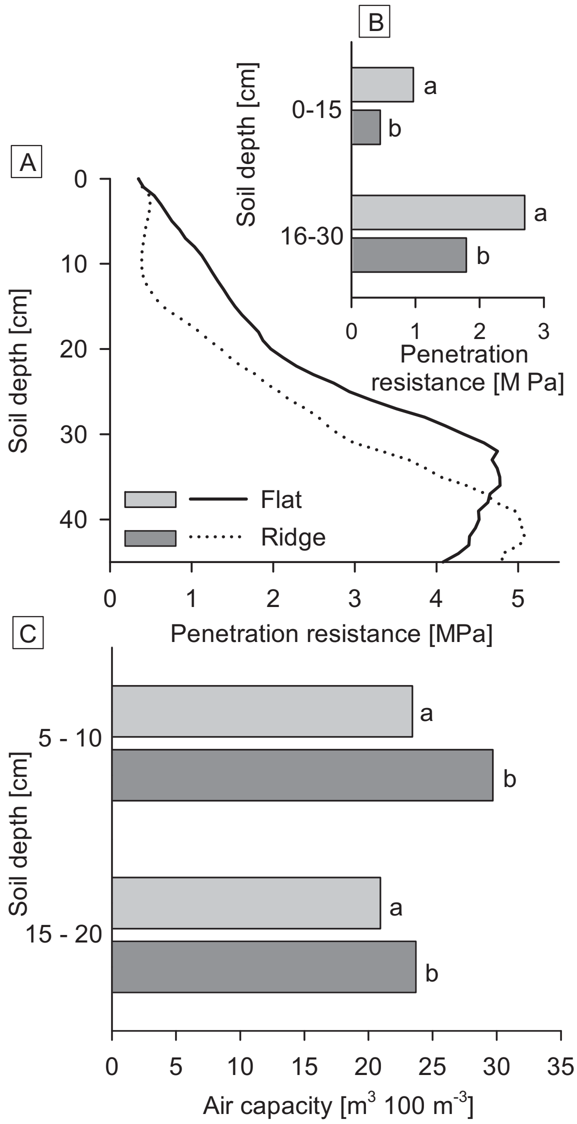

Fig. 2: Effect of flat and ridge cultivation of sugar beet on penetration resistance down to 45 cm depth (A), mean penetration resistance in 0-15 cm and 16-30 cm depth (B), and air capacity in 5-10 cm and 15-20 cm depth (C); mean of sowing dates 1 and 2; 2006 and 2007; different letters within one column group indicate significant differences between cultivation treatments (*F*-Test, $\alpha \leq 0.05$).

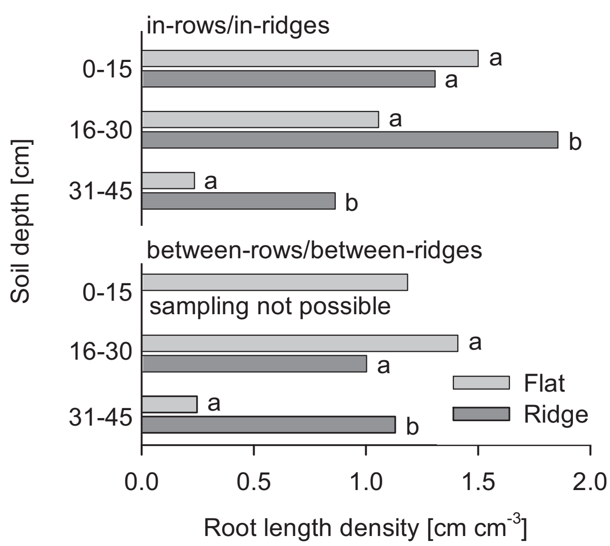

Fig. 3: Effect of flat and ridge cultivation of sugar beet on root length density in 0-15 cm, 16-30 cm and 31-45 cm soil depth in-rows/in-ridges and between-rows/between-ridges; mean of 2006 and 2007; samples were taken in July in plots of sowing date 2; different letters within one column group indicate significant differences between cultivation treatments (*F*-Test, $\alpha \leq 0.05$).

In 0-30 cm depth, N_{min} content at in-rows/in-ridges position was highest at the middle of April and continuously decreased until August (Fig. 4). Until end of May, the amount of N_{min} was significantly lower in flat (89-78 kg ha^{-1}) than in ridge (129-104 kg ha^{-1}) cultivation. Subsequently, no cultivation treatment effects occurred. In 30-60 cm depth, N_{min} content was lower than in the soil layer above from April to June, thereafter values were equal (Fig. 4). N_{min} content increased from the middle of April until end of May and decreased afterwards. Flat cultivation revealed significantly lower N_{min} values than ridge cultivation from April to May.

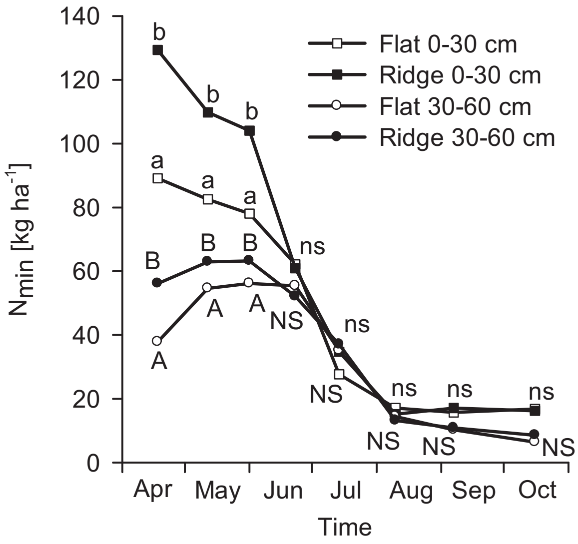

Fig. 4: N_{min} content at in-rows/in-ridges position during the growing season in 0-30 cm and 30-60 cm depth as effected by flat and ridge cultivation; soil samples were taken in plots of sowing date 1; mean of 2006 und 2007; different letters indicate significant differences between cultivation treatments at one sampling date for one soil depth (*F*-Test, $\alpha \leq 0.05$); ns, NS: not significant.

Number of days after sowing until 50 % relative field emergence was significantly lower in ridge cultivation (Fig. 5A), consequently sugar beet emerged 1 to 4 days earlier in ridge than in flat cultivation. Total plant DMY from May to October was lower after flat compared to ridge cultivation (Fig. 5B, 5C). Total plant DMY in August was composed from beets and leaves to about one half each, whereas in October beets accounted for 70 to 80 % of total plant DMY (Fig. 5C). At August and October harvests, ridge cultivation significantly increased beet but not leaf DMY. WSY was significantly lower after flat compared to ridge cultivation (Fig. 5D).

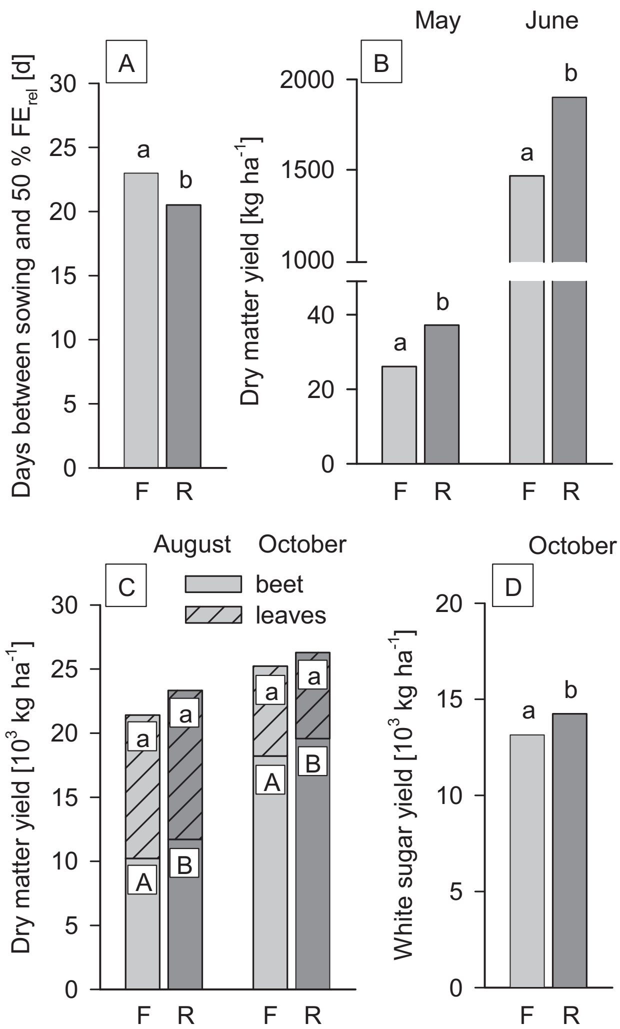

Fig. 5: Effect of flat (F) and ridge (R) cultivation of sugar beet on number of days between sowing and 50 % relative field emergence (50 % FE_{rel}; A), total plant dry matter yield in May (4-6-leaf-stage) and June (canopy closure, B), August and October (C), and white sugar yield in October (D); mean of sowing dates 1 and 2; 2006 and 2007; different letters within one column group indicate significant differences between cultivation treatments (*F*-Test, $\alpha \leq 0.05$).

N content of plant DM was highest in May (ca. 50 g kg^{-1}) and slightly decreased in June, whereas values considerably fell down to ca. 20 g kg^{-1} in August and October (Fig. 6). In May, cultivation treatment had no significant effect on N content. From June to October it was slightly lower in flat compared to ridge cultivation. Differences were significant in June and October.

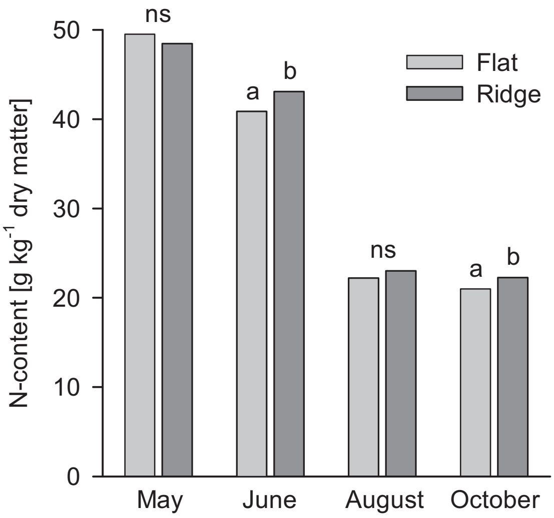

Fig. 6: Effect of flat and ridge cultivation of sugar beet on N content in the total plant dry matter in May and leaf dry matter in June, August and October; mean of sowing dates 1 and 2; 2006 and 2007; different letters within one column group indicate significant differences between cultivation treatments (*F*-Test, $\alpha \leq 0.05$); ns: not significant.

P content of plant DM was highest in May (7.2 g kg^{-1}), diminished until August (3.5 g kg^{-1}) and slightly increased again in October (4.1 g kg^{-1}; not shown). In May, values were significantly lower in ridge compared to flat cultivation, while subsequent cultivation treatment effects were not significant. K content increased from May (84 g kg^{-1}) to June (94 g kg^{-1}), but considerably decreased to August and October (44 g kg^{-1}; not shown). There was a tendency to higher K content in ridge compared to flat cultivation during the whole growing season, however differences were not significant.

CGR substantially increased from the first (CGR_1, sowing-May) to the third (CGR_3, June-August) interval and fell down from August to October (CGR_4) to values similar to CGR_2 (May-June; Fig. 7). CGR_1 and CGR_2 were significantly higher at ridge compared to flat cultivation, which was not the case for CGR_3 and CGR_4.

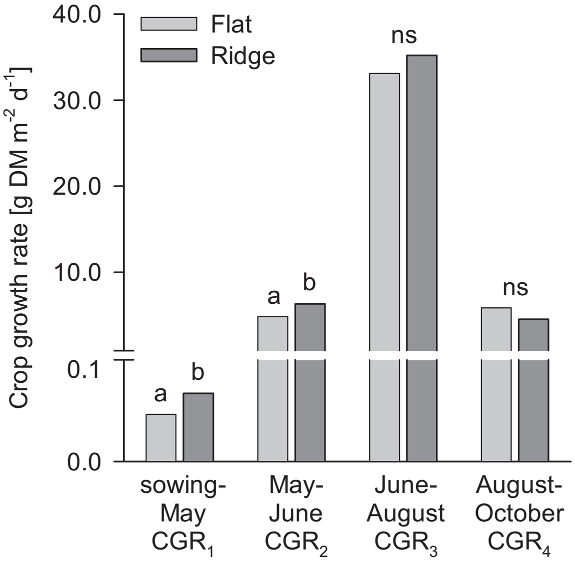

Fig. 7: Effect of flat and ridge cultivation of sugar beet on crop growth rate (CGR) over the growing season; mean of sowing dates 1 and 2; 2006 and 2007; different letters within one column group indicate significant differences between cultivation treatments (*F*-Test, α ≤ 0.05); ns: not significant.

The coefficients of Spearman's rank correlation revealed significant negative correlations between TT_1 and TT_2 and PR from both depth, whereas TT_3 and TT_4 positively correlated with PR (both depth; Table 2). $AC_{5\text{-}10}$ and $AC_{15\text{-}20}$ positively correlated with TT_1 and TT_2, but were negatively related to TT_3 and TT_4. Within and between soil layers, PR and AC were negatively correlated to each other. $CGR_{1\text{-}2}$ were positively correlated with TT_1 (CGR_1), TT_2 (CGR_2), $AC_{5\text{-}10}$ and $AC_{15\text{-}20}$, but negatively with $PR_{0\text{-}15}$ and $PR_{16\text{-}30}$. Similar relations were found for $CGR_{3\text{-}4}$ to AC and PR, but not to $TT_{3\text{-}4}$, which were negatively correlated to the respective growth rate.

Based on the results of the correlation analysis, essential relations of CGR to soil physical parameters were presented in Figure 8. The relation between CGR_1 and TT_1, and CGR_2 and $PR_{0\text{-}15}$ was best described by linear regression. The higher TT_1 and the lower $PR_{0\text{-}15}$, the higher was CGR_1 and CGR_2, respectively.

Table 2: Coefficients of Spearman's rank correlation between sugar beet crop growth rate (CGR_1 = sowing to 4-6-leaf-stage in May; CGR_2 = May to canopy closure in June; CGR_3 = June to August; CGR_4 = August to October), corresponding thermal time ($TT_{1\text{-}4}$; °C d), penetration resistance in 0-15 and 16-30 cm soil depth ($PR_{0\text{-}15}$, $PR_{16\text{-}30}$) and air capacity in 5-10 and 15-20 cm soil depth ($AC_{5\text{-}10}$, $AC_{15\text{-}20}$); data centred for sowing date and year; correlation coefficients with $|r| > 0.35$ are significant at $\alpha = 0.05$ and marked with bold font.

	TT_1	TT_2	TT_3	TT_4	$PR_{0\text{-}15}$	$PR_{16\text{-}30}$	$AC_{5\text{-}10}$	$AC_{15\text{-}20}$
$PR_{0\text{-}15}$	**-0.89**	**-0.57**	**0.76**	**0.94**				
$PR_{16\text{-}30}$	**-0.57**	**-0.94**	0.10	**0.61**	**0.56**			
$AC_{5\text{-}10}$	**0.75**	**0.70**	**-0.45**	**-0.76**	**-0.73**	**-0.67**		
$AC_{15\text{-}20}$	**0.46**	**0.42**	-0.21	**-0.39**	**-0.39**	**-0.38**	**0.40**	
CGR_1	**0.86**				**-0.83**	**-0.64**	**0.62**	**0.39**
CGR_2		**0.56**			**-0.75**	**-0.62**	**0.63**	0.20
CGR_3			-0.12		-0.35	**-0.40**	0.35	0.16
CGR_4				**-0.51**	**-0.48**	-0.13	**0.37**	0.18

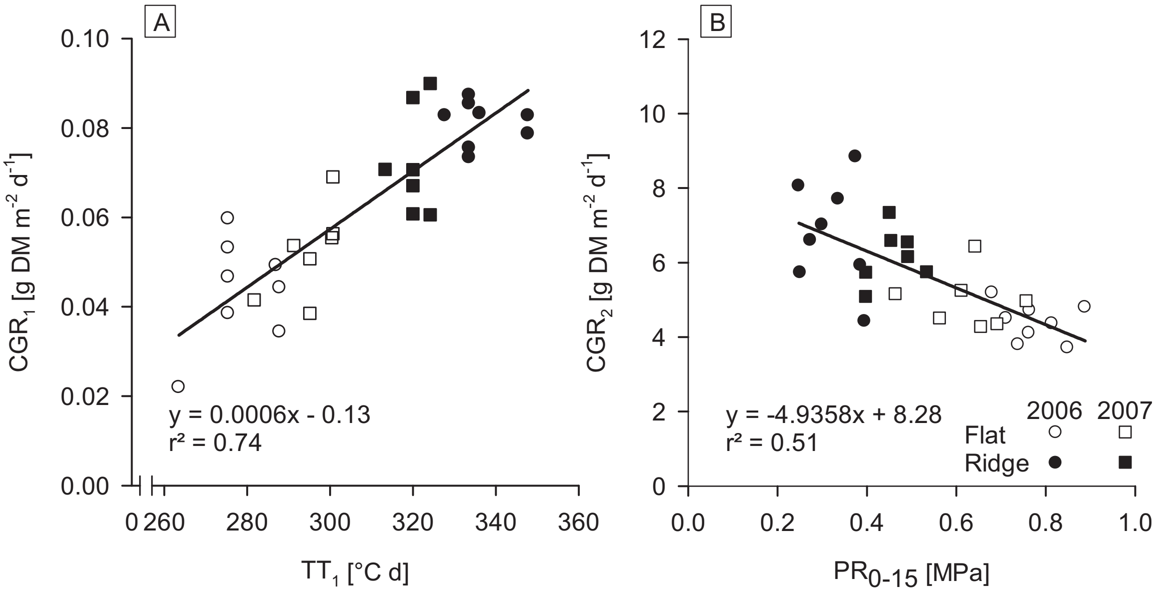

Fig. 8: Regression between sugar beet crop growth rate from sowing to 4-6-leaf-stage in May (CGR_1) and corresponding thermal time (TT_1, A), and crop growth rate from May to canopy closure in June (CGR_2) and penetration resistance in 0-15 cm depth ($PR_{0\text{-}15}$, B); data centred for sowing date and year; mean of 2006 und 2007. Regressions are significant at $\alpha \leq 0.001$.

4. Discussion

Ridge compared to flat cultivation has shown to increase final beet yield and WSY by 5 to 10 % on numerous sites located in northern Germany (Schlinker et al., 2007). In contrast, comparisons made in the Rhineland area (western Germany), which is characterised by higher spring temperatures, revealed no clear yield increase due to ridge cultivation. Similarly, Krause et al. (2008) presented data from an experiment conducted in 2006 on a loessial site in the Uelzen region, where sugar beet yield was equal under flat and ridge cultivation. In that experiment sowing was delayed until early May followed by elevated soil temperatures (>10 °C), presumably explaining the lack of yield effects. Those results indicate the importance of climate and soil parameters for the effect of ridge cultivation on the growth of sugar beet.

Sugar beet growth varies during the growing season according to species specific patterns of growth and development as effected by environmental conditions (Hoffmann, 1997; Kenter, 2003). Differences in CGR of sugar beet between flat and ridge cultivation may arise from factors such as soil moisture, temperature, oxygen and nutrient supply, that were effected by the cultivation technique applied. Therefore, the relations between CGRs and soil parameters will subsequently be discussed to identify the processes and cause-and-effect mechanisms relevant for the yield increase due to ridge cultivation. Other factors such as fertilisation and the occurrence of pests and diseases, that may also influence CGRs were kept constant for both cultivation treatments. With regard to soil physical properties, this study will substantially contribute to the understanding of growth limiting factors in sugar beet cultivation in temperate climate.

Plant growth from sowing to 4-6-leaf-stage in May

During early plant growth, CGR_1 significantly correlated with TT_1, PR_{0-15}, AC_{5-10}, PR_{16-30} and AC_{15-20} in descending order from $|r| = 0.86$ to $|r| = 0.39$. Obviously, properties of the uppermost layer of the soil are of major importance, which can be derived from the much closer correlations obtained for the 0-15 cm compared to the 16-30 cm layer, thereby sustaining the results of Garz et al. (1992) and Scott and Jaggard (1993). Consequently, discussion focuses on AC_{5-10} and PR_{0-15}, followed by TT_1.

AC was measured to characterise the root oxygen supply, which accomplishes an important role for germination and subsequent plant growth processes (Al-Ani et al., 1985). For sandy topsoils, AC values of at least 15 m^3 100 m^{-3} were reported as optimal for sugar beet growth (Czeratzki, 1972), which was considerably exceeded by AC_{5-10} in ridge (29.7 m^3 100 m^{-3}) and flat cultivation (23.4 m^3 100 m^{-3}). Therefore, limitation of oxygen supply was most unlikely responsible for the observed differences in CGR_1 between cultivation treatments.

PR_{0-15} characterises soil strength, which may influence root growth (Liebhard, 1997) and thereby, nutrient and water uptake, and hormonal activity of plants (Feldman, 1984; Helal, 1991). Materechera et al. (1991) reported on > 90 % reduction of root growth of several mono- and dicotyledonous crop species at a soil strength of 4.2 MPa. According to Bengough (1992), root elongation can be slowed by 20 to 75 % at a PR of 1.5 MPa, depending on crop and soil type. Liebhard et al. (1995) and Atwell (1993) found a maximum of ca. 1.8 MPa for unimpeded root penetration of sugar beet, maize and wheat. In our study, PR_{0-15} in ridge (ca. 0.5 MPa) and flat (ca. 1.0 MPa) cultivation was below these threshold values and thus, presumably did not constrain root elongation during the early growth phase in any treatment. But, later in the growing season decreasing soil moisture may substantially have increased PR (Coelho et al., 2000).

Low values of PR may indicate a poor soil-root contact, which can hamper nutrient and water uptake by the plant (Helal, 1991). Bergmann (1993) reported 40 to 60 g N kg^{-1} DM, 35 to 60 g K kg^{-1} DM and 3.5 to 6.0 g P kg^{-1} DM as adequate for unlimited sugar beet growth. Values refer to medium sugar beet leaf blades taken 50 to 60 days past field emergence, whereas the presented data were analysed out of the complete plant 30 to 35 days past emergence. Due to nutrient dilution during plant growth (Draycott, 2006), the minimum threshold value must be assigned higher at earlier growth stages, but lower taking into account the lower N-concentration in complete plants compared to leaf blades. Values applicable for immediate comparison with our data are not available in literature. At May harvest, concentration of N accounted for ca. 49 g N kg^{-1} DM and concentration of K for ca. 84 g K kg^{-1} DM in the plant in both ridge and flat cultivation. Thus, values of N and K in the plant DM were likely not limiting plant growth. The P content in the plant DM at May harvest was significantly different between flat (7.5 g P kg^{-1} DM) and ridge cultivation (6.9 g P kg^{-1} DM), nevertheless both values exceeded P content adequate for sugar beet growth.

N mineralisation in the soil is promoted by high temperatures and soil loosening by tillage as applied during ridge forming (Kladivko and Keeney, 1987; Franzluebbers and Arshad, 1996). Consequently, N_{min} content in 0-30 cm during CGR_1 period was higher in ridge compared to flat cultivation. Although N demand of sugar beet seedlings is low during early plant growth and uptake only amounts to ca. 20 kg N ha^{-1} by the middle of May, adequate N supply is crucial for fast canopy development (Draycott and Christenson, 2003). In our experiments, N supply in 0-30 cm depth clearly exceeded this amount in both cultivation treatments. Obviously, differences in N supply did not contribute to treatment effects on CGR_1, as also fortified by the equal N-concentration in the plant DM of both cultivation treatments.

Furthermore, in our study water content of the 0-15 cm soil layer was higher in flat compared to ridge cultivation at an absolute level of 15 to 20 m^3 100 m^{-3} during April and May (Krause et al., 2008). This gives proof, that limited water supply of plants grown in flat cultivation can be excluded as cause for lower CGR_1. Conclusively, data show no limitation of early growth due to restricted water and nutrient supply for both cultivation treatments.

Mechanical stress exerted to roots can be detected by root caps and transmitted to leaves by hormonal signals, thereby causing stomatal closure, reduced photosynthesis rate and consequently limited plant growth (Tardieu et al., 1991; Mulholland et al., 1996; Masle, 1998). In our study, the hormonal status of plants was not determined, but due to low values of $PR_{0\text{-}15}$ in both ridge and flat cultivation, growth restrictions by hormonal effects are very unlikely during early sugar beet growth until May. Nevertheless, threshold values for severity of soil strength influencing the hormonal status of plants are not specified in literature.

From sowing to 4-6-leaf-stage, effects on CGR_1 are composed of effects caused by date of field emergence and moreover, intensity of subsequent seedling growth. Firstly, an increase in soil temperature stimulates the pace of field emergence (Scott et al., 1973; Gummerson, 1986; Campbell and Enz, 1991). In our study, 50 % relative field emergence was achieved 1-4 days earlier in ridge compared to flat cultivation, and mean soil temperature from the beginning of measurements to May harvest was raised up to 1.8 °C higher in ridge compared to flat cultivation.

Simultaneously, $AC_{5\text{-}10}$ was increased by ca. 6 m^3 100 m^{-3}, while water content in 0-15 cm depth was decreased by ca. 5 m^3 100 m^{-3} in ridge compared to flat cultivation. Air located in the pores has a much less heat capacity than soil solids and water (Guérif et al., 2001) and therefore, high amounts of soil air enhance soil warming. Presented data show a close correlation of $AC_{5\text{-}10}$ with TT_1 and water content. Furthermore, the enlarged soil surface in ridge cultivation has likely advanced absorption of incident heat radiation, due to the more favourable angle of incidence for sunrays at ridge legs compared to flat soil.

In addition to temperature influence on germination and field emergence, soil temperature impacts early growth of sugar beet (Hoffmann and Jungk, 1996). Pot experiments conducted under controlled conditions revealed diminished plant growth at 10 °C compared to 20 °C in the rooting zone, even if above ground temperature was 20 °C in both treatments. From this it can be concluded that, in addition to accelerated germination, higher temperatures in ridge compared to flat cultivated soil promoted early sugar beet growth, and thereby contributed to higher yield in May and CGR_1 obtained in ridge cultivation.

Conclusively, TT_1 revealed the closest correlation with CGR_1 among all parameters included in this analysis. Temperature obviously was the most limiting factor for early sugar beet growth and development. However, correlation analysis reveals strong collinearity between TT_1, PR_{0-15} and AC_{5-10}, indicating the close interconnection between single soil parameters, which hampers clear elucidation of cause-and-effect mechanisms between soil parameters and plant growth (Wiersum, 1957; Liebhard, 1997; Koch et al., 2008).

Plant growth from 4-6-leaf-stage in May to canopy closure in June

For the period from May to June, ridge compared to flat cultivation significantly increased CGR_2. Strongest impact on CGR_2 emanated from PR_{0-15}, followed by AC_{5-10} and TT_2 ($|r| = 0.75$ to $|r| = 0.56$). Correlation between CGR_2 and soil structural parameters in 16-30 cm depth was less close compared to the layer above, emphasising the predominant influence of the uppermost soil horizon on crop growth from May to June as it was found for CGR_1.

In contrast to the previous period, temperature (TT_2) appeared to be of minor effect on CGR_2 compared to PR, which may be attributed to period dependant differences in both, the soil temperature level and the magnitude of temperature differences between treatments. Ehlers (1980) described the importance of a plant's specific optimal growth temperature: the closer actual related to optimal temperature, the faster growth processes take place and, the smaller is the stimulating effect of an additional temperature increase. 3 °C is regarded minimum for sugar beet growth (Milford et al., 1985), the optimal temperature is between 17 to 24 °C (Terry, 1968). For the CGR_1 period, mean daily soil temperature was 7.0 °C in ridge and 6.1 °C in flat cultivation, whereas during CGR_2 period temperature was considerably higher and differences had almost disappeared (ridge 13.8 °C, flat 13.6 °C). Presumably, developing leaf canopy increased shadowing of the soil surface, which diminished the effect of higher heat radiation absorption and convection in ridge cultivation.

For evaluation of the influence of AC and PR on CGR_2 it has to be regarded that soil parameters have been measured several weeks earlier than crop growth. Nevertheless, soil data were regarded significant to evaluate potential effects of oxygen, water and nutrient supply, and hormonal balance of plants (Feldman, 1984; Helal, 1991) on CGR_2.

As discussed earlier, high values of AC indicate, that oxygen supply during May and June was probably not limiting crop growth and thus, did not contribute to differences between cultivation treatments in CGR_2.

Besides texture and dry bulk density, soil moisture strongly effects PR: values increase with decreasing soil water content as regularly occurs in temperate climate during the plant's water uptake over the growing season (Taylor et al., 1966; Eavis, 1972; Vaz et al., 2001). In our study, PR measurements were carried out in spring when soil moisture was high. Thus, it is to assume that PR_{0-15} and PR_{16-30} increased during the study period and differences between cultivation treatments became more pronounced (Knittel and Stanzel, 1976; Borchert and Graf, 1988), influencing CGR_2 of flat and ridge cultivation.

PR was determined as an indicator for soil strength effecting root growth, which was measured as RLD. According to Garz et. al. (1992) and Windt (1995), final RLD in the topsoil (0-30 cm) is established at the time of canopy closure. Subsequently, RLD data of this layer can be assumed to remain constant over summer. Therefore, RLD (0-15 cm, 16-30 cm) determined at mid July is applicable for growth analysis at June harvest as well. In-rows/in-ridges RLD in 0-15 cm depth was equal between cultivation treatments. Obviously, higher PR_{0-15} in flat compared to ridge cultivation did not constrain root growth, although absolute level of PR_{0-15} values and treatment differences were assumed to increase as discussed before. In contrast to the layer above, RLD in 16-30 cm depth of in-rows/in-ridges position clearly reflected treatment effects on PR_{16-30}: flat cultivation significantly increased PR and decreased RLD. Absolute level of PR and differences due to cultivation treatments were in a range that suppose effects on root growth (Liebhard et al., 1995), especially when taking into account increasing PR values due to decreasing soil water content over time. RLD at between-rows/between-ridges position in 16-30 cm depth tended to be lower in ridge compared to flat cultivation. This trend was likely caused by the missing roots in the soil layer above coming along with ridge cultivation.

However, differences in RLD between cultivation treatments have to be evaluated with regard to their potential for limiting water and nutrient uptake by plants. Across treatments, N content in plant DM was higher at May harvest compared to June harvest due to dilution effects coming along with an increase in structural and storage tissues that contain little N (Greenwood et al., 1991). N-concentration in leaf DM at June harvest was significantly higher in ridge compared to flat cultivation. According to Bergmann (1993), 43 to 59 g N kg^{-1} DM, 35 to 66 g K kg^{-1} DM and 3.2 to 6.2 g P kg^{-1} DM are adequate for optimum sugar beet growth at the end of June. In ridge cultivation, N in leaf DM (43.1 g N kg^{-1} DM) was at the lower limit, while in flat cultivation (40.7 g N kg^{-1} DM) it was slightly below the given limit range. As discussed earlier, differences in leaf sample composition between the study of Bergmann (1993) and ours must be taken into account for data evaluation. Thus, it is to conclude that N supply was probably adequate in both treatments, but it cannot be totally excluded that N-deficiency slightly limited growth in flat cultivation. Moreover, P content in leaf DM of both cultivation treatments was within the range, while K content exceeded the range for adequate sugar beet growth. Therefore, P and K deficiency are excluded as growth limiting factors for the period from May to June.

Similarly, differences in water supply were likely not the cause for the lower CGR_2 in flat compared to ridge cultivation. Soil water content during May and June was ca. 5 m^3 100 m^{-3} higher in flat than in ridge cultivation. Finally, changes in the plants hormonal status due to mechanical stress may have caused differences in CGR_2 between ridge and flat cultivation as previously discussed for CGR_1 (Masle, 1998; Hartung et al., 2002). Although no data on hormonal status of plants are available, increased PR down to 30 cm depth, reduced in-rows RLD in 16-30 cm depth and diminished DMY at June harvest in flat compared to ridge cultivation support this hypothesis.

Plant growth from June to October

In the periods from June to August (CGR_3) and August to October (CGR_4) crop growth did not significantly differ between cultivation treatments, and correlations to soil parameters were much less close than those from the periods before. CGR_3 correlated just weakly with PR_{16-30} (r = -0.40), no other soil parameter revealed a significant relation to crop growth. For CGR_4, significant correlations occurred with TT_4 (r = -0.51), PR_{0-15} (r = -0.48) and AC_{5-10} (r = 0.37).

To conclude, higher root DMY in ridge cultivation measured in August, and higher DMY and WSY in October originated from enhanced sugar beet growth during the early phases of the growing season until June.

Conclusions

Higher yield of sugar beet can be obtained by ridge compared to conventional flat cultivation. Ridge forming increased soil temperature after sowing and enhanced field emergence and further growth until June. From sowing to May, soil temperature appeared to be the most effective factor determining sugar beet growth. Due to evolving leaf canopy during early growth until June, impact of soil temperature on CGR_2 declined and the importance of PR in 0-15 cm depth on root growth and root activity increased. $CGR_{3/4}$ from June to October was not different between cultivation treatments. Conclusively, the basis of higher final yield in ridge cultivation was established during early growth until June, primarily caused by warmer soil and growth stimulating soil structure. Relative DMY increase in ridge cultivation was 38.7 % for May harvest and 29.7 % for June harvest. Yield increase diminished during the growing season and advanced WSY in autumn to 8.4 % in ridge compared to flat cultivation of sugar beet. Results are appraised as indicative for other than sandy soils as well, but yield differences may be less pronounced in regions with a warmer spring climate. For a comprehensive evaluation of ridge cultivation of sugar beet, it must be regarded that the potential yield increase has to cover the higher input of energy and machinery, and the lower area capacity at sowing. In economic terms, the yield increase attainable with ridge cultivation is likely to outbalance the higher costs under current northern German conditions. But, in future decreasing sugar beet returns as well as increasing energy costs may diminish the competitiveness of ridge cultivation. Advancing of machinery and other aspects of the ridge cultivation system (autumn ridges) may help to overcome these constraints.

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4. Epilog

Alternative im Zuckerrübenanbau: Herbstdämme

Einleitung

In Norddeutschland durchgeführte Versuche zum Dammanbau von Zuckerrüben haben gezeigt, dass Mehrerträge von bis zu 10 % gegenüber dem konventionellen Flachanbau möglich sind (GRAPE 2002, GRAPE et al. 2004, KRAUSE et al. 2008). Nach einer aktuellen Berechnung von SCHLINKER et al. (2007) werden die höheren Verfahrenskosten des Dammanbaus bei einem Mehrertrag von 5 bis 7 % kompensiert und der Deckungsbeitrag erhöht. Dennoch ist der intensive Maschineneinsatz, der hohe Arbeitskraftbedarf und die allgemein geringe Flächenleistung des Verfahrens Damm bei der bislang üblichen, kombinierten Dammformung und Aussaat im Frühjahr ein Hindernis für dessen Einführung in die praktische Landwirtschaft. Die Aussaat kann statt wie im Flachanbau mit 12- oder 18-reihigen Drillmaschinen und einer Arbeitsgeschwindigkeit von ca. 10 km h^{-1} im Verfahren Damm nur 6-reihig mit einer Arbeitsgeschwindigkeit von nur ca. 5 km h^{-1} bei hohem Zugkraftbedarf (> 150 kW) durchgeführt werden. Zudem fällt die Zuckerrübenaussaat im Frühjahr in eine Zeit hoher Arbeitsbelastung.

Das Vorziehen der Dammformung in den Herbst könnte zur Entzerrung der Arbeitsspitze im Frühjahr beitragen und die Akzeptanz und Verbreitung des Dammanbaus in die Praxis fördern. Herbstdämme könnten die Schlagkraft im Frühjahr erhöhen, da nur noch in die bereits vorgeformten Dämme ausgesät werden müsste. Die vorgeformten Herbstdämme trocknen vermutlich im Frühjahr zeitiger ab als die flache Bodenoberfläche, so dass eine frühere Aussaat ohne Gefährdung der Bodenstruktur möglich wäre. Untersuchungen zur Dammformung im Herbst in Mitteleuropa liegen bislang aber nur für den Kartoffelanbau vor (SCHOLZ 1986, HÄGE 1993). Ein weiterer Vorteil des Verfahrens Herbstdamm könnte die intensivere N-Mineralisation infolge erhöhter Bodentemperaturen im Herbst sein und eine

Verhinderung der N-Auswaschung über den Winter durch den Anbau von Zwischenfrüchten auf den Herbstdämmen. Im späten Herbst geformte Dämme könnten dabei einen günstigeren Effekt auf den N-Haushalt haben, da bei Dammformung im zeitigen Herbst, bei Temperaturen über 5 °C und vor dem Einsetzen ausgiebiger Herbstniederschläge, N-Mineralisation und N-Verlagerung in tiefere Bodenschichten gefördert werden (HENRIKSEN et al. 2007).

Erste Erfahrungen aus dem 2006 begonnenem Exaktversuch (KRAUSE et al. 2008) zum Vergleich der Anbauverfahren Flach und Damm verdeutlichten die arbeitswirtschaftlichen Schwierigkeiten von Dammformung und Aussaat im Frühjahr. Vor diesem Hintergrund wurde ein einjähriger Versuch (2007) zum Vergleich des Zuckerrübenanbaus in den Verfahren früher Herbstdamm (HDa), später Herbstdamm (HDb), Frühjahrsdamm (D) und Flach (F) auf einem Sand- (Suderburg) und einem Lössstandort (Natendorf) in der Region Uelzen (Niedersachsen) durchgeführt. Ziel war es, die variantenspezifische Bodenerwärmung im Frühjahr, den Verlauf des Feldaufgangs und den Einfluss des Anbauverfahrens auf den Ertrag zu untersuchen und die Ergebnisse zwischen den Verfahren zu vergleichen. Von besonderem Interesse war dabei die Frage, ob bei Anbau von Zuckerrüben im Herbstdamm ein ähnlicher Mehrertrag wie im Verfahren Frühjahrsdamm erreicht werden kann.

Material und Methoden

Die Herbstdämme wurden im Herbst 2006 mit einem 6-reihigen Dammformgerät mit Diabolorollen vorgeformt. Dabei lockerte ein Zinkenrotor den Boden, nahm ihn auf und führte ihn nachfolgenden Formblechen und angetriebenen Walzen zu, die den Damm formten und rückverfestigten. Es wurden zwei verschiedene Varianten von Herbstdämmen angelegt. Variante Herbstdamm a: Der Damm wurde nach der Stoppelbearbeitung der Vorfrucht Anfang September geformt und die Zwischenfrucht manuell auf und zwischen die Dämme gesät und flach eingearbeitet. Auf den restlichen Parzellen der Versuchsanlage wurde die Zwischenfrucht maschinell gesät. Variante Herbstdamm b: Das organische Material der

Zwischenfrucht wurde im späten Herbst (November) gemulcht und das Zwischenfruchtmaterial bei der Dammformung in die Dämme eingearbeitet. Auf den verbleibenden Parzellen wurde das Zwischenfruchtmaterial ebenfalls gemulcht (Tab. 1). Im Frühjahr erfolgte die Aussaat auf den Herbstdämmen ohne weitere Bearbeitung. In den Varianten Flachanbau und Frühjahrsdamm wurde der Boden unmittelbar vor der Saat 14 cm tief mit einem Grubber bearbeitet. Dammformung und Aussaat der Frühjahrsdämme wurde in einer Überfahrt durchgeführt. Die Aussaat erfolgte in allen Varianten am selben Tag. Ammonnitrat-Harnstofflösung wurde unter Berücksichtigung des N_{min}-Gehaltes im Frühjahr und des Zwischenfruchtanbaus vor der Aussaat auf einen Sollwert von 140 kg N ha^{-1} ausgebracht (LWK NIEDERSACHSEN 2008). Pflanzenschutzmaßnahmen wurden innerhalb der Versuchsstandorte einheitlich ausgeführt und entsprachen den regionalen Empfehlungen. Die Versuchsdurchführung erfolgte in Suderburg und Natendorf in Form eines vollständig randomisierten lateinischen Rechtecks mit vier Wiederholungen.

Die Bodentemperatur wurde mit Temperaturfühlern Pt100 wie von KRAUSE et al. (2008) beschrieben in 3-5 cm Bodentiefe erfasst. Die Messungen begannen in den Varianten Flach und Herbstdamm a vor der Aussaat ab dem 07.03.2007 und wurden nach der Aussaat auch im Verfahren Frühjahrsdamm ermittelt. Die im Verfahren Herbstdamm a gemessene Bodentemperatur wurde als repräsentativ für die Bodentemperatur des Verfahrens Herbstdamm b betrachtet. Daten zur Lufttemperatur in 2 m über der Erdoberfläche wurden von der meteorologischen Station Stöcken bei Uelzen zur Verfügung gestellt. Eine Feldaufgangszählung wurde im Abstand von ein bis zwei Tagen während der Feldaufgangsperiode durchgeführt (Tab. 1) und der Zeitpunkt des Erreichens von 50 % relativem Feldaufgang ermittelt (KRAUSE et al. 2008). Zur Ertragsbestimmung wurde Mitte Oktober eine Fläche von 10 m² je Parzelle mit einem einreihigen Parzellenroder beerntet. Rübengewicht und Qualitätsparameter wurden ermittelt und der Bereinigte Zuckerertrag (BZE) nach MÄRLÄNDER et al. (2003) berechnet.

Tab. 1: Pflanzenbauliche Maßnahmen und Datenerhebung bei Anbau von Zuckerrüben im Flachanbau, Frühjahrsdamm, zeitiger Herbstdamm und später Herbstdamm; Suderburg und Natendorf, 2007.

	Suderburg	Natendorf
Pflanzenbauliche Maßnahmen		
Vorfrucht	Wintertriticale (*Triticosecale*)	Winterweizen *(Triticum sativum)*
Zwischenfrucht	Gelbsenf (*Sinapis alba*)	
Aussaat Zwischenfrucht	08.09.2006	
Dammformgerät	Dammformgerät (Struik) mit Zinkenrotor, Formblechen und Diabolorollen	
Aussaat Flach	18-reihig	
Aussaat Damm	6-reihig, an Dammformgerät angebaut	
Dammformung Herbst (früh)	08.09.2006	
Dammformung Herbst (spät)	02.11.2006	
Saattermin	15.03.2007	02.04.2007
Feldkapazität (%) in 0-15 cm Tiefe	87	84
Datenerhebung		
Feldaufgang	04.04.-30.04.2007	14.04.-30.04.2007
Ernte Oktober	16.10.2007	16.10.2007

Ergebnisse

Die Bodentemperatur vor der Aussaat im Frühjahr wurde während der Messperiode im Verfahren Herbstdamm a gegenüber dem Flachanbau erhöht und erreichte eine mittlere Bodentemperatur von 6,81 °C (HDa) gegenüber 6,72 °C (F) in Suderburg und 6,66 °C (HDa) gegenüber 6,29 °C (F) in Natendorf (Abb. 1). In Suderburg wurden nach der Aussaat während der Feldaufgangsperiode im Verfahren Frühjahrsdamm bis zu 2,0 °C und im Verfahren Herbstdamm a bis zu 1,9 °C höhere Tagesmitteltemperaturen als im Flachanbau ermittelt. In Natendorf waren die Temperaturunterschiede während des Feldaufgangs zwischen den Varianten ähnlich und lagen im Verfahren Frühjahrsdamm bis zu 1,9 °C und im Herbstdamm a bis zu 1,7 °C über den Tagesmitteltemperaturen im Flachanbau.

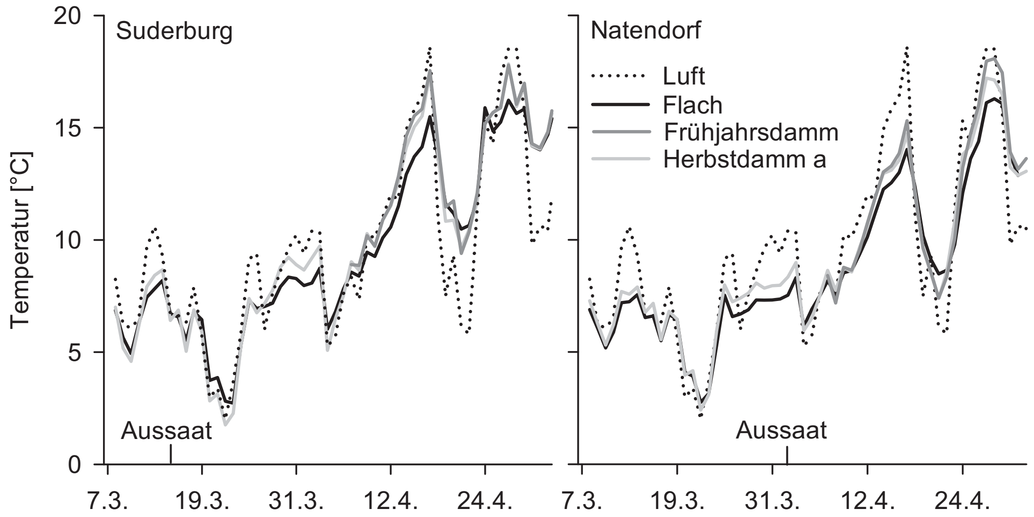

Abb. 1: Verlauf von Lufttemperatur (2 m Höhe) und Bodentemperatur (3-5 cm Tiefe) bei Anbau von Zuckerrüben in den Verfahren Flach, Frühjahrsdamm und Herbstdamm a; Zeitspanne zwischen 7.3.2007 und 2.5.2007; Suderburg (Sand) und Natendorf (Löss), 2007.

Der Feldaufgang wurde an beiden Standorten in den Verfahren Frühjahrsdamm, Herbstdamm a und Herbstdamm b gegenüber dem Flachanbau beschleunigt (Abb. 2). In Suderburg wurde 50 % relativer Feldaufgang in den Verfahren Frühjahrsdamm, Herbstdamm a und Herbstdamm b nach 24 Tagen und im Flachanbau nach 26 Tagen erreicht, während in Natendorf 14 (D, HDa, HDb) bzw. 13 (F) Tage benötigt wurden.

In Suderburg wurde der höchste BZE im Oktober im Verfahren Herbstdamm a (14,2 t ha^{-1}) erzielt, gefolgt vom Verfahren Frühjahrsdamm (13,5 t ha^{-1}), Herbstdamm b (13,2 t ha^{-1}) und Flachanbau (12,7 t ha^{-1}) mit dem geringsten Ertrag (Abb. 3). Die Erträge lagen damit mit 11,8 % (HDa), 6,3 % (D) und 3,9 % (HDb) über dem BZE im Flachanbau, jedoch war der Ertrag nur zwischen den Verfahren Herbstdamm a und dem Flachanbau signifikant verschieden. In Natendorf wurde der höchste BZE im Verfahren Herbstdamm b ermittelt (16,0 t ha^{-1}). Der BZE im Verfahren Frühjahrsdamm (15,8 t ha^{-1}) und Herbstdamm a (15,7 t ha^{-1}) war nur geringfügig, im Flachanbau deutlich niedriger (15,0 t ha^{-1}; Abb. 3), wobei die Unterschiede zwischen den Anbauverfahren bei Mehrerträgen von 6,7 % (HDb), 5,3 %

(D) und 4,7 % (HDa) gegenüber dem Flachanbau nicht signifikant voneinander verschieden waren.

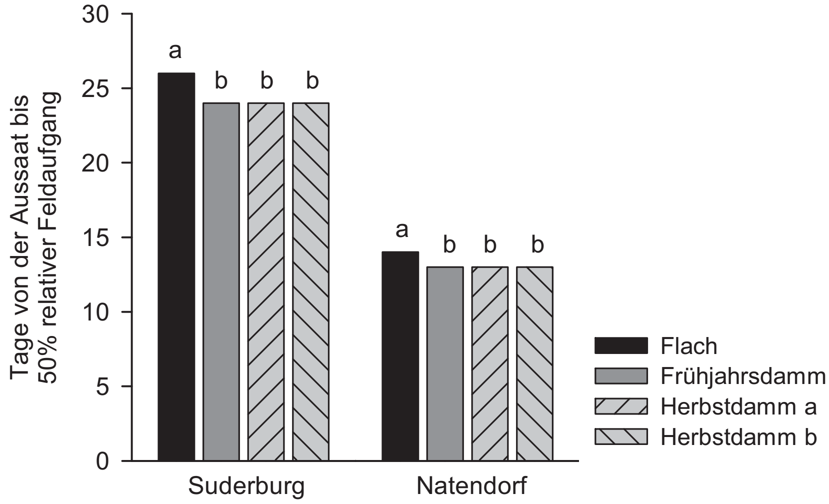

Abb. 2: Einfluss der Anbauverfahren Flach, Frühjahrsdamm, Herbstdamm a und Herbstdamm b auf die Anzahl Tage zwischen Aussaat und 50 % relativen Feldaufgang von Zuckerrüben; Suderburg (Sand) und Natendorf (Löss), 2007; Buchstaben geben signifikante Unterschiede innerhalb eines Versuchs an (Tukey, α ≤ 0,05).

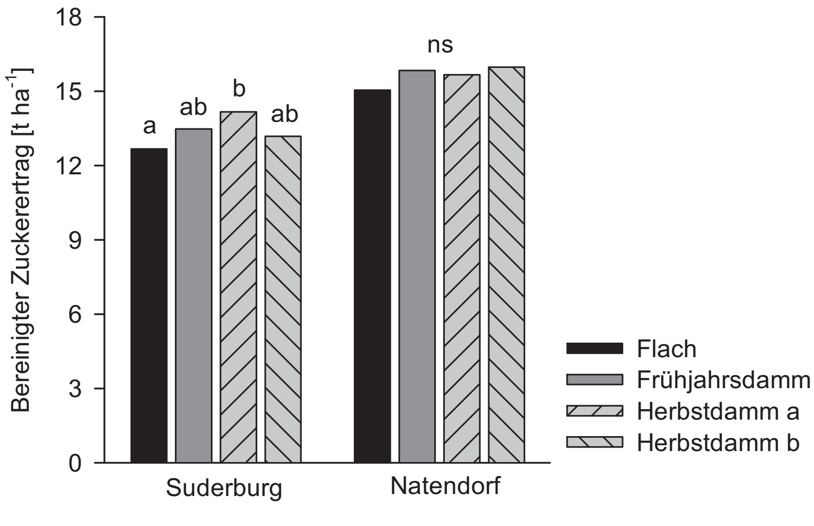

Abb. 3: Bereinigter Zuckerertrag zur Endernte im Oktober in Suderburg (Sand) und Natendorf (Löss), 2007; Buchstaben geben signifikante Unterschiede innerhalb eines Versuchs an (Tukey, α ≤ 0,05), ns = nicht signifikant.

Diskussion

Die Ergebnisse der Bodentemperaturmessung zeigen, dass die Vorverlegung der Dammformung in den Herbst bereits vor der Aussaat im Frühjahr zu einer Erhöhung der Bodentemperatur gegenüber der flachen Bodenoberfläche führte. Daten zur Bodenfeuchte liegen für diesen Zeitraum zwar nicht vor, jedoch ist davon auszugehen, dass die höhere Temperatur im Verfahren Herbstdamm a einherging mit einem geringeren Wassergehalt. Bei einer zeitigeren Abtrocknung des Saathorizontes im Herbstdamm wäre die Aussaat in den Verfahren Herbstdamm a und b bei gleichwertigen Bedingungen im Saatbett wie im Flachanbau zu einem früheren Termin möglich. Eine zu diesem Zeitpunkt in der Dammfurche höhere Bodenfeuchte als in der Dammkrone birgt zwar die Gefahr von Bodenverdichtungen zwischen den Herbstdämmen, jedoch wäre der Wuchsraum der Zuckerrüben frei von Radspuren und Verdichtungen.

Die Bodentemperatur im Verfahren Herbstdamm a war nach der Aussaat ähnlich hoch wie im Verfahren Frühjahrsdamm. Die in den Dämmen um 1,7-2,0 °C höhere Tagesmitteltemperatur als im Flachanbau beschleunigte die Keimung und führte zu einem schnelleren Erreichen von 50 % relativem Feldaufgang in den Varianten Frühjahrsdamm, Herbstdamm a und b. Der in allen Dammvarianten beobachtete zügigere Feldaufgang und die beschleunigte Pflanzenentwicklung erhöhten den BZE zur Endernte um bis zu 11,8 % gegenüber dem Flachanbau. Im Mittel der beiden Versuchsstandorte wurde durch die Vorverlegung der Dammformung in den Herbst ein um durchschnittlich 6,8 % höherer BZE gegenüber der konventionellen Flachsaat erzielt. Jedoch konnten im einjährigen Vergleich standortbezogen keine eindeutigen signifikanten Unterschiede zwischen den Anbauverfahren herausgestellt werden. Die Ergebnisse unterstreichen allerdings, dass die Herbstdämme im Vergleich zum Flachanbau eine ähnliche Ertragssteigerung wie das Verfahren Frühjahrsdamm bewirken. Ertragsunterschiede zwischen den Varianten Herbstdamm a und Herbstdamm b waren nicht erkennbar. Günstigere Bodenbedingungen für die Dammformung im Herbst sind allerdings für den frühen Herbstdamm zu erwarten. Bei der späten Dammformung im Herbst können aufgrund des vorhergehenden Zwischenfruchtanbaus und einer daraus resultierenden beträchtlichen Menge an organischem Material in Verbindung mit hoher Bodenfeuchte technische Probleme bei der Dammformung entstehen. Vorteilhafter erscheint daher eine frühe Dammformung Anfang September mit anschließender Zwischenfruchtaussaat.

Schlussfolgerungen

Das Vorziehen der Dammformung in den Herbst stellt eine Alternative dar, die ertragserhöhenden Effekte des Dammanbaus auszuschöpfen und die Organisation der Frühjahrsbestellung zu erleichtern. Im Frühjahr zeitiger abtrocknende Dämme könnten eine frühere Aussaat ermöglichen und die Zeitspanne für die Bestellung der Zuckerrübe und andere Arbeitsgänge verlängern.

5. Fazit

Beim Anbau von Zuckerrüben kann ein angepasstes Anbauverfahren dazu beitragen, das standortspezifische Ertragspotenzial optimal auszuschöpfen. In der vorliegenden Arbeit wurde daher der Ertragseffekt des konventionellen Flachanbaus von Zuckerrüben mit dem Dammanbau verglichen. Von besonderem Interesse war dabei der Einfluss unterschiedlich feuchter Bodenbedingungen bei der Aussaat auf wichtige Bodeneigenschaften und den Verlauf der Ertragsbildung in den Verfahren Flach und Damm.

In einem zweijährigen Feldversuch auf einem Sand- und Lössstandort in Norddeutschland wurden die Parameter Bodentemperatur und -wassergehalt, mineralischer Bodenstickstoff, Eindringwiderstand und Luftkapazität des Bodens erhoben. Zur Ermittlung des Zusammenhanges von Bodenparametern und dem Verlauf des Pflanzenwachstums wurde der Feldaufgang ermittelt, die Wurzellängendichte gemessen und Zeiternten durchgeführt. Ertrags- und Qualitätsparameter sowie der Gehalt an Stickstoff, Kalium und Phosphor in den Pflanzen wurden bestimmt.

Der Dammanbau von Zuckerrüben stellt eine Möglichkeit dar, den Ertrag gegenüber dem Flachanbau zu steigern. Ein höherer Ertrag im Verfahren Damm als im Flachanbau wurde erzielt, wenn die Bodentemperatur in der Auflaufphase und Jugendentwicklung durch die Dammformung deutlich erhöht war (0,5-1 °C). Die höhere Bodentemperatur im Dammanbau beschleunigte den Feldaufgang und das Jugendwachstum der Zuckerrübe. Der wachstumsfördernde Effekt der Temperaturerhöhung durch den Damm war umso größer, je niedriger das Ausgangsniveau der Bodentemperatur nach der Aussaat war. Bei hohem Niveau der Bodentemperatur von deutlich über 10 °C führte der Dammanbau nicht zu einer Ertragssteigerung. Den größten Einfluss auf das Wachstum der Zuckerrübe hatte die Bodentemperatur in dem Zeitraum von der Aussaat bis in den Mai. Infolge des sich entwickelnden Blattapparates und der dadurch zunehmenden Beschattung ging der Einfluss der Bodentemperatur danach zurück und die Bedeutung des Eindringwiderstandes (0-15 cm Tiefe) für das Pflanzenwachstum stieg an. Nach dem Reihenschluss im Juni war der Verlauf des Zuckerrübenwachstums in den Anbauverfahren Damm und Flach gleich. Die vorgestellten Ergebnisse zeigen, dass die Grundlage des höheren Ertrages im Dammanbau während der Jugendentwicklung gebildet wurde und in einem Mehrertrag von 7-9 % gegenüber dem Flachanbau resultierte.

Eine Bearbeitung und Aussaat bei sehr hoher Bodenfeuchte kann auf Lössstandorten die Ausbildung einer verschlämmten und verkrusteten Oberflächenschicht nach sich ziehen, die Feldaufgang und Wachstum behindern kann. Daher sind keine Vorteile durch eine Vorverlegung des Saatzeitpunktes im Verfahren Damm bei Bedingungen mit sehr hoher Bodenfeuchte zu erwarten, wenn zum standortspezifisch optimalen Saattermin sichergestellt ist, dass der Wasserbedarf der Samen für Keimung und Feldaufgang gedeckt wird. Der Einfluss des Saatzeitpunktes, also der Bodenfeuchte zur Aussaat, blieb ohne Effekt auf den Ertrag im Herbst.

Unterschiede in der Höhe des Ertragseffektes durch Dammanbau zwischen Sand- und Lössböden bestehen offensichtlich nicht, jedoch ist davon auszugehen, dass geringere Ertragsunterschiede in Regionen mit einer wärmeren Frühjahrswitterung als an den Versuchsstandorten auftreten.

Für die Evaluierung des Dammanbaus von Zuckerrüben müssen der zu erwartenden Ertragssteigerung die höheren Kosten gegenübergestellt werden. Möglichkeiten der maschinen- und verfahrenstechnischen Weiterentwicklung des Dammanbaus, wie das Vorziehen der Dammformung in den Herbst, sollten dabei Beachtung finden.

Der Dammanbau von Zuckerrüben konzentriert sich in Deutschland bislang auf die Region Dithmarschen in Schleswig-Holstein. Die dortigen Marschböden erwärmen sich im Frühjahr sehr langsam und profitieren in besonderem Maße von der Vergrößerung der Bodenoberfläche bei der Dammformung. In den vorgestellten Exaktversuchen wurde der Ertrag durch Damm- im Vergleich zum Flachanbau erhöht und führte auch bei den parallel durchgeführten Streifenversuchen zu einem ähnlichen Ergebnis. Dennoch konnte sich das

Verfahren Dammanbau über die Versuchslaufzeit hinaus in der Region Uelzen nicht etablieren. Vor allem die höheren Kosten für die Dammformung verbunden mit ungenügenden Kenntnissen über die Ertragssicherheit des Dammanbaus verhinderten die Übernahme des Verfahrens durch die Landwirte. Das Ergebnis dieser Arbeit hat jedoch gezeigt, dass in der Region Uelzen/Norddeutschland ein höherer Ertrag durch den Dammanbau erzielt werden kann. Eine Möglichkeit, die hohe Arbeitsbelastung im Frühjahr zu reduzieren, konnte durch das Vorziehen der Dammformung in den Herbst aufgezeigt werden.

Für Norddeutschland ist der Dammanbau von Zuckerrüben ein attraktives Anbauverfahren, das einen höheren Deckungsbeitrag als der konventionelle Flachanbau erreichen kann, wenn der höhere Arbeitskraftbedarf in den Betriebsablauf integriert und die Aussaat Mitte März bis Anfang April realisiert werden kann. Die Unterstützung durch landwirtschaftliche Beratungsstellen und die Bereitstellung des Dammformgerätes über einen Maschinenring würde die Etablierung des Dammanbaus von Zuckerrüben fördern.

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