Nachrichtenbl. Deut. Pflanzenschutzd., **58** (3), S. 73–78, 2006, ISSN 0027-7479.

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Aspects of straw mulching in organic potatoes – I. Effects on microclimate, *Phytophthora infestans*, and *Rhizoctonia solani*

Aspekte der Strohmulchanwendung im ökologischen Kartoffelanbau – I. Wirkung auf Mikroklima, *Phytophthora infestans* und *Rhizoctonia solani*

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Abstract

The application of straw mulch in potatoes is a possible strategy for soil erosion control, virus control and reduction of post-harvest soil nitrate losses. In this study, the effects of mulching on severity of late blight (*Phytophthora infestans* [MONT.] DE BARY) and black scurf (*Rhizoctonia solani* KÜHN) were assessed in organically managed field experiments over three years at four sites in Germany. Late blight severity was assessed in 15 of the experiments as percentage of infected leaf area or percentage of leaves with late blight lesions. Black scurf on harvested tubers was assessed on 100 to 220 tubers per plot in 18 experiments. In addition, effects of straw mulch on air temperature, relative humidity and evaporation in the potato stand were measured in two of the experiments. Straw mulch had no significant effect on late blight severity in most of the experiments, but a trend of late blight reduction through the application of straw mulch was observed in 13 out of 15 experiments. Black scurf was not influenced by straw mulch, with effects being non-significant in 16 out of 17 experiments. Effects of straw mulch on microclimate within the crop canopy were dependent on the time of the day, with the air in mulched plots being slightly moister and cooler at night and dryer and warmer during the day. This effect was pronounced in the fortnight directly after mulching and became less marked in the period four to six weeks thereafter. In one experiment a consistent decrease of evaporation was observed over four weeks.

Key words: Late blight, black scurf, organic farming, potato, straw mulch

Zusammenfassung

Die Anwendung von Strohmulch als eine mögliche Strategie zur Reduzierung von Bodenerosion, Virusinfektionen und Nachernte-Stickstoffverlusten in Kartoffeln wurde hinsichtlich der Effekte auf die Krautfäule (*Phytophthora infestans* [MONT.] DE BARY) und auf die Pockenkrankheit (*Rhizoctonia solani* KÜHN) in ökologisch geführten Feldexperimenten über drei Jahre an vier Standorten in Deutschland untersucht. Der Krautfäulebefall wurde in 15 Versuchen als Prozent befallener Blattfläche oder Prozent der Blätter mit Läsionen bonitiert. *Rhizoctonia*-Pocken auf den geernteten Knollen wurden bei 100 bis 220 Knollen pro Parzelle in 18 Feldversuchen bonitiert. Zusätzlich wurde in einem Feldversuch der Einfluss von Strohmulch auf die Lufttemperatur und die relative Luftfeuchte sowie, in einem weiteren Versuch, auf die Verdunstung im Kartoffelbestand gemessen. In 12 von 15 Feldversuchen hatte Strohmulch keinen signifikanten Einfluss auf die Befallsschwere der Krautfäule. Allerdings konnte in 13 von 15 Feldversuchen ein Trend zur Reduktion von Krautfäule durch Strohmulch beobachtet werden. Der Befall mit *Rhizoctonia* wurde von Strohmulch nicht beeinflusst, in 16 von 17 Feldversuchen waren die Effekte nicht signifikant. Die Effekte von Strohmulch auf das Mikroklima im Bestand waren von der Tageszeit abhängig. Nachts war die Luft in den gemulchten Parzellen geringfügig feuchter und kühler, am Tag jedoch etwas trockener und wärmer als in den Parzellen ohne Strohmulch. Dieser Effekt war in der 14-tägigen Periode direkt nach dem Mulchen deutlicher, und in der Periode 4 bis 6 Wochen danach weniger ausgeprägt. In einem Versuch wurde über vier Wochen eine konsistente Verringerung der Verdunstung im Kartoffelbestand durch Mulchen beobachtet.

Stichwörter: Kartoffel, Krautfäule, Pockenkrankheit, Ökologischer Landbau, Strohmulch

Introduction

The application of straw mulch to various agricultural crops is an ancient practice (KING, 1984), serving a variety of aims, such as moisture conservation (JAMES, 1945; MOOERS et al., 1948), weed suppression (HEMBRY and DAVIES, 1994), or improvement of soil organic matter status (JACKS et al., 1955). In potatoes, straw mulch application was practised in the early 20th century in North America (KNOWLTON et al., 1938; ROWE-DUTTON, 1957), but disappeared from commercial growing and is now only used to some extent in home gardening. However, experimental evidence suggests that straw mulch could improve environmentally and economically important aspects of commercial potato growing, as straw mulch was repeatedly shown to massively reduce soil erosion (EDWARDS et al., 2000; DÖRING et al. 2005). Moreover, benefits of straw mulch regarding virus vector control in seed potatoes have been reported (EMERSON, 1907; HEIMBACH et al., 2000; HEIMBACH et al., 2002; SAUCKE and DÖRING, 2004). Finally, straw mulch may also act as a tool for the control of nitrogen losses by immobilisation of post-harvest soil nitrate (CHRISTENSEN and OLESEN, 1998; DÖRING et al., 2005).

In order to assess the prospect for the re-adoption of this cultural technique, it is necessary to investigate possible side effects of straw mulch on plant health and tuber quality. Two of the most important diseases in current organic potato production are late blight and black scurf (MÖLLER et al., 2003; TAMM et al., 2004). Late blight, caused by *Phytophthora infestans,* is commonly considered to be one of the most important yield limiting factors in organic potato production (TAMM et al., 2004; but see MÖLLER, 2002). Also, *Rhizoctonia solani* is a severe problem in organic potato growing, because infestation with black scurf, i.e. sclerotia on the tubers that cannot be removed by washing, reduces marketability of ware potatoes. Moreover, sclerotia on seed potatoes serve as inoculum in the field, potentially reducing the emergence of the crop considerably (e.g., POWELSON et al., 1993).

In this paper we summarise the effects of straw mulch on late blight and black scurf based on the results from field experiments conducted at four sites over three years. This is the first study known to the authors dealing with the response of these two diseases to straw applied as a mulch after crop emergence in potatoes. Effects on yield, virus transmission, and the infestation with the Colorado potato beetle are reported in a second paper in this journal (DÖRING et al., 2006).

Material and methods

Field experimental design

Over three years, 20 field experiments were conducted on four organically managed farms in Germany: (A) The experimental farm of the University of Kassel at Eichenberg (silty loam soil); (B) an arable farm at Etzenborn near Göttingen (sandy loam); (C) A mixed farm at Dibbesdorf near Braunschweig (loamy sand); and (D) a mixed farm at Lühburg near Rostock (sand). Dates for planting, mulching and harvest, as well as plot sizes and precrops are presented in Table 1. In the experiments at site A, B and D, mulching with straw was compared to non-mulching, whereas in the three experiments at site C (6, 12 and 19), an additional third treatment with a higher amount of straw was included. In experiments 1, 2, 6, 11, 12, 13, 19, and 20, seed preparation (presprouting) or the level of initial virus infection was included as an additional treatment factor. As there were no significant interactions between these factors and mulching in any case, they are disregarded in this paper. All experiments at sites A, B, and D were conducted in randomised complete block designs with four replications, with the exception of exp. 3, 4 and 11, where 3, 8 and 8 replications were used, respectively. At site C, all experiments were conducted in a strip plot design.

Microclimatic measurements

The development of late blight is strongly dependent on high humidity (STEVENSON, 2001). Therefore, the influence of straw mulch on microclimate, including relative humidity was investigated. Microclimatic measurements were done with Hobo data loggers (Onset Ltd.) in experiment 1 (2002, site A). The device was protected from direct insolation by an aluminium roof (ca. 18 × 17 cm). In four mulched and four unmulched plots (paired within blocks), one logger per plot was placed on top of the ridge between two representative plants in the centre of the plot.

The air temperature and relative humidity were measured every 10 min (i.e., t = 6 * 24 = 144 times per day) at 15 cm above ground in three periods of 15 days, with period 1 from 24 May (shortly after mulching) to 7 June; period 2 from 8 June to 22 July; and period 3 from 23 June to 7 July, the last date being the time of approximately maximum crop cover (ca. 80 %). Data processing was done in three steps. First, for each Hobo logger pair, the differences at each time between mulched and unmulched plots were calculated and averaged over all blocks. Second, a two-hourly moving average was applied to these differences in order to smooth the data. Third, using these smoothed differences, the average for each time of the t times of the day, within each of the first and last 15-day-period was calculated, in order to establish the development of the mulch effect on microclimate depending on the time of the day. Standard errors refer to the variation between days within each period with constant time of the day.

Table 1. Details of experiments: plot size, planting, mulching and harvesting date, mulch quantity, length harvested per plot and precrop (location of experimental sites see text)

Exp.	Year	Site	Variety	Plot size (m x m)	Planting date	Mulching date	Mulch (t/ha)[b]	Date of harvest	m harvested per plot	Precrop[d]	Numbering in Döring et al. 2006[e]
1	2002	A	Christa	9 × 9	10. 4.	16. + 26 .5.[a]	5.0	14. + 16. 8.[c]	63	grass-clover	4
2	2002	A	Nicola	9 × 9	15. + 20. 5.	3. + 10. 6.[a]	4.0	23. + 24. 9.[c]	63	grass-clover	5
3	2002	B	Christa	9 × 30	5. 4.	17. 5.	3.5	5. 8	27	carrots	6
4	2002	B	Nicola	15 × 25	8. 4.	17. 5.	3.5	28. 8.	15	winter wheat	7
5	2002	B	Nicola	3 × 25	8. 4.	17. 5.	3.5	28. 8.	15	winter wheat	8
6	2002	C	Linda	45 × 45	4. 4.	15. + 16. 5.	3.6/7.3	19. 8.	45	barley, rye + oil radish	–
7	2002	D	Linda	51 × 49	22. 4.	24. 6.	(1.5)	14. 8.	(25)	grass-legume ley	–
8	2002	D	Marabel	36 × 49	22. 4.	24.6.	(1.5)	14. 8.	(25)	grass-legume ley	–
9	2003	A	Marabel	24 × 18	17. 4.	28. 5.	3.0	3. 9.	15	summer wheat	9
10	2003	A	Rosella	18 × 30	17. 4.	28. 5.	3.0	4. 9.	15	cabbage	10
11	2003	B	Nicola	30 × 27.5	15. 4.	21. 5.	3.0	26. 8.	48	peas	12
12	2003	C	Linda	37 × 40	27. 3.	8.–10. 5.	5.5/8.5	21. 8.	30	barley, rye + oil radish	–
13	2003	D	Linda	45 × 45	22. + 23. 4.	12. 6.	2.0	12. 8	(25)	grass-legume ley	–
14	2004	A	Marabel	15 × 13.5	2. 4.	28. 5.	5.0	7. 9.	25	grass-clover	–
15	2004	A	Simone	13.5 × 13.5	2. 4.	28. 5.	5.5	7. 9.	25	grass-clover	–
16	2004	B	Christa	9 × 30	31. 3.	18. 5.	5.0	–	–	grass-clover	–
17	2004	B	Nicola	12 × 20	19. 4.	24. 5.	5.0	4. 9.	25	winter wheat	–
18	2004	B	Nicola	12 × 20	19. 4.	24. 5.	5.0	4. 9.	25	winter wheat	–
19	2004	C	Linda	33 × 50	31. 3	11. 5.	2.6/3.7	7. 9.	30	spring barley + peas	–
20	2004	D	Linda	30 × 60	22. + 23. 4.	3. 6.	2.3	12. 8.	(25)	grass-legume ley	–

[a]: earlier date in presprouted, later date in non-presprouted potatoes. No significant interaction between mulch and presprouting regarding *Phytophthora* or *Rhizoctonia*.
[b]: ±0.25t/ha; for experiment 6, 12, and 19, the first figure gives the lower amount of straw, the second figure after the slash is the higher amount.
[c]: harvest of mature tubers occurred blockwise on two dates; haulms had already died back completely before harvest.
[d]: green manure over winter after winter cereals.
[e]: Results on yields, N-dynamics, and weeds of these experiments were reported there.

Table 2. Effect of straw mulch on severity of late blight (*Phytophthora infestans*), measured (1) as diseased leaf area on a single date (DLA); (2) as relative area under disease progress curve of diseased leaf area (RAUDPC(a)); (3) as the percentage of infected leaves on a single date (incidence); or (4) as the RAUDPC(i) based on the percentage of infected plants over time

Parameter	Exp.	Error df	Assessments first	last	nr.	Assessement value Unmulched	Mulched	Trend of difference Mulched – Unmulched[b]		Block effect
DLA (%)	6[a]	3	5. 7.	5. 7.	1	17. 5	5.2	–	*	ns
	14	3	28. 7.	28. 7.	1	5. 8	3.3	–	ns	ns
	15	3	4. 8.	4. 8.	1	15. 5	10.5	–	ns	ns
	17	3	28. 7.	28. 7.	1	48. 5	42.5	–	**	ns
	18	3	28. 7.	28. 7.	1	52.0	46.4	–	ns	ns
RAUDPC (a)	1	9	21. 6.	6. 8.	6	28. 2	26.4	–	ns	***
	2	9	21. 6.	6. 8.	6	2.7	2.3	–	ns	***
	4	7	13. 5.	21. 8.	6	7.4	7.2	–	ns	**
	9	3	25. 6.	22. 7.	3	4.9	3.0	–	ns	ns
	16	3	2. 6.	28. 7.	7	13.5	9.9	–	ns	ns
	19[a]	6	9. 7.	20. 7.	3	36.5	36.2	–	ns	ns
	20	7	5. 7.	22. 7.	3	24. 2	26.0	+	*	**
Incidence (%)	6[a]	3	2. 7	2. 7.	1	68.5	34.5	–	*	ns
	7	3	18. 6.	18. 6.	1	33.3	31.1	–	ns	ns
	8	3	18. 6.	18. 6.	1	19.8	17.3	–	ns	ns
	13	(7)	28. 7.	28. 7.	1	5.1	8.4	+	ns	ns
RAUDPC (i)	19[a]	6	29. 6.	20. 7.	5	37.2	35.9	–	ns	ns

+: infection level higher in mulched treatment; –: infection level lower in mulched treatment; [a] For reasons of better readability, the treatment with lower mulch amount is omitted from the table; [b] *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

Late blight is known to be favoured by temperatures of about 15–22 °C and relative humidity of > 90 % (e.g., MINOGUE and FRY, 1981). Therefore, for both the mulched and the unmulched treatment we calculated the number of sampling times per day (out of 144) that met these microclimatic conditions.

In addition, evaporation within the potato crop was determined in experiment 19 with 4 pseudoreplications between 7 June 2004 and 6 July 2004. In this period, mean air temperature was 15.4 °C, with 57.2 mm rainfall. On 2 July 2004, estimated mean crop cover was 53 % (SD = 11 %). Four vials per treatment were filled with 9 ml water and placed at a height of 15–20 cm above ground. Water evaporated from green paper discs which were protected from direct insolation. The evaporation from these vials was read out as ml water dayly (24 ± 3 h between readings) and normalised to ml per 24 h.

Late blight and black scurf assessments

Late blight severity was assessed in 15 of the field experiments with three different parameters. In experiments 1, 2, 4, 9, 16, 19, and 20, the percentage of diseased leaf area (DLA) in 1–10 subplots of 3 × 3 m per plot was estimated from the onset of infection until complete haulm death in intervals of one to two weeks (Table 2). In experiments 6, 14, 15, 17, and 18, disease assessments as percent DLA were made only once. In addition to infected leaf area assessments, the percentage of potato leaves with late blight lesions (count of infected leaves/total number of leaves*100) was chosen as a second parameter in order to reduce possible observer bias (experiment 6, 7, 8, and 13). Finally, the incidence of diseased plants as a parameter appropriate for low infection levels was assessed regularly in experiment 19.

Black scurf severity of harvested tubers was assessed in 18 of the experiments (Table 3). After sorting the harvested tubers into three fractions (< 35 mm, 35–55 mm and > 55 mm), 100–220 tubers per plot were chosen randomly from the middle fraction. Tubers were thoroughly washed and then assessed with a key (LYRE, 1982), classifying the tubers into five classes according to the percentage of the tuber area infested with sclerotia: 0 %, 1–4 %, 5–9 %, 10–14%, and ≥ 15 %.

Table 3. Effect of straw mulch on tuber infestation with *Rhizoctonia solani* sclerotia, expressed as disease severity index i_{Rs} and percentage of uninfected tubers p_0.

Exp.	error df	tubers assessed	Means *R. solani*-index Unmulched	Mulched		Means "uninfected" (%) Unmulched	Mulched		Mulching effect on *R.solani* (trend)
1	9	1566	0.13	0.13	ns	94.8	94.9	ns	–
2	9	3357	1.97	2.71	*	46.4	35.0	*	+
3	2	1339	2.33	0.82	ns	45.7	68.3	ns	–
4	7	1869	0.11	0.13	ns	96.6	95.1	ns	+
5	3	877	0.27	0.18	ns	90.3	95.4	ns	–
7	3	800	0.50	1.40	ns	84.3	67.4	ns	+
8	3	798	1.48	1.44	ns	74.4	75.0	ns	–
9	3	993	1.60	1.94	ns	65.7	60.9	ns	+
10	3	1000	1.91	2.20	ns	53.5	52.7	ns	+
11	21	3191	1.04	1.04	ns	74.8	70.4	ns	+
12[a]	6	1600	1.20	1.15	ns	58.9	61.3	ns	–
14	3	1175	1.38	1.34	ns	46.1	54.9	ns	–
15	3	1146	1.85	2.12	ns	28.0	24.6	ns	+
16	3	1680	1.43	1.19	ns	52.0	54.5	ns	–
17	3	1200	1.16	1.36	ns	72.5	71.0	ns	+
18	3	1173	1.30	1.25	ns	59.5	65.1	ns	–
19[a]	6	2400	0.30	0.37	ns	75.9	73.5	ns	+

*: $0.01 < p < 0.05$; +: infection level higher in mulched treatment; –: infection level lower in mulched treatment; [a] For reasons of better readability, the treatment with lower mulch amount is omitted from the table. The figures from the mulched treatment of experiment 6, 12, and 19 represent the higher amount.

Data processing and statistical analysis

Late blight disease development over time was summarised by first calculating the area under the disease progress curve (AUDPC) (Kranz, 1996, p. 181). In order to remove year and site effects and the fact that assessments were conducted over different time periods in the different experiments, a relative AUDPC (RAUDPC) was calculated for each experiment. This was done by dividing the attained AUDPC by the possible maximum AUDPC. This $AUDPC_{max}$ is the product of 100 % and the number of days between the first and last disease assessment and therefore gives the AUDPC for the theoretical case that the disease had been continuously 100 % from the start of the epidemic.

For black scurf, a disease severity index i_{Rs} was calculated using the following equation: $i_{Rs} = \Sigma n_j c_j/N$, where c_j = the lower limit of the j^{th} infestation class, n_j = number of tubers in the j^{th} infestation class, and $N = \Sigma n_j$. The possible maximum of i_{Rs} is 15 %. As a measure of disease incidence the percentage p_0 of uninfested tubers was chosen ($p_0 = \Sigma n_0/N*100$). Both indices were calculated per plot (not per subsample).

Statistical analyses were performed with SAS v6.12 (SAS Institute Inc., 1989; SAS Institute Inc., 1990). Percentage values were arcsin-square-root transformed; untransformed data are presented. Data transformation did not change significance levels in any case. For the statistical analysis of a variable over a set of experiments, the sign test after Dixon and Mood (Sachs, 1999, p. 414) was used; a pair of observations consisted of the mean of the mulched treatment over all replications and the mean of the unmulched treatment.

Results

Microclimate

In the first fortnight period shortly after mulching, the air temperature within the potato stands was higher in the mulched plots than in the unmulched plots during the day (roughly between 7:00 and 17:00 h), but lower in the mulched than in the unmulched plots during the night (Fig. 1). Whereas the nightly cooling effect of mulch was also observed four weeks later in the last period, the effect of higher air temperature caused by straw mulch during the day was less marked in the last period than in the first. For both periods however, temperature differences were generally low, amounting to a maximum positive difference of +0.44 K (at 11:30 h, period 1) and a maximum negative difference of –0.42 K (at 18:30 h, period 3).

The effect of mulch on relative humidity was small, and, compared to the effect on air temperature, showed a reversed pattern

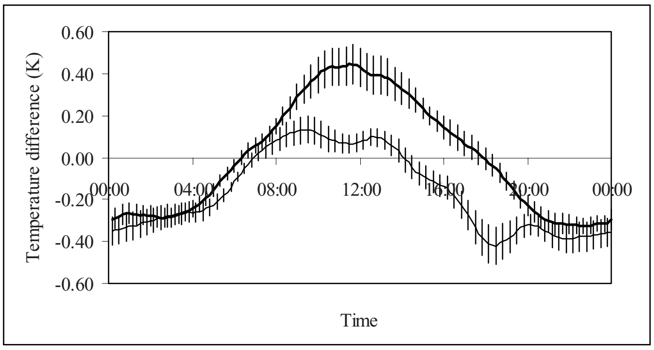

Fig. 1. Effect of straw mulch on air temperature in potato stands shown as the temperature difference (M–C) between mulched (M) and unmulched treatment (C). Bold line: directly after mulching (period 1): fine line four weeks later (period 3, dates see text); means ± SE. For reasons of better readability only every second SE-Bar is presented.

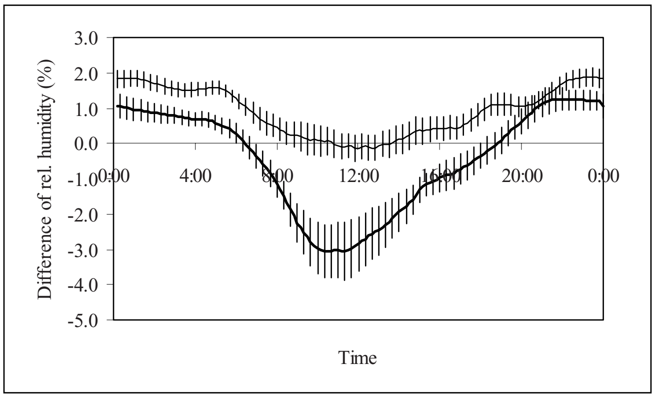

Fig. 2. Effect of straw mulch on relative air humidity in potato stands shown as the humidity difference (M–C) between mulched (M) and unmulched treatment (C) treatment. Bold line: directly after mulching (period 1): fine line four weeks later (period 3, dates see text); means ± SE. For reasons of better readability only every second SE-Bar is presented.

(Fig. 2). In the first period, the air within the potato stands was dryer during the day (maximum negative difference of –3.1 % at 10:30 h), but moister during the night (maximum positive difference of 1.2 % at 21:50 h). In the last period, effects during daytime were levelled out with no significant difference between relative humidity in mulched and unmulched plots. However, night time differences were somewhat greater than in the first period, with the mulched plots being moister (maximum difference 1.9 %, at 23:30 h).

The first late blight lesions on the leaves in this experiment were observed after a week of microclimatic conditions that were comparatively conducive to late blight development (on average, 9 hours per day with rH > 90 % and air temperatures of 15–22 °C), while in the following two weeks the conditions were less favourable for late blight (3 and 1 conducive hours per day, respectively).

In experiment 19, the evaporation from vials placed in the potato crop was consistently lower in the mulched than in the unmulched treatment over approx. 4 weeks (Fig. 3), with the lowest evaporation occurring at the highest mulch quantity. This effect was more pronounced during day time and less visible in the night (data not presented).

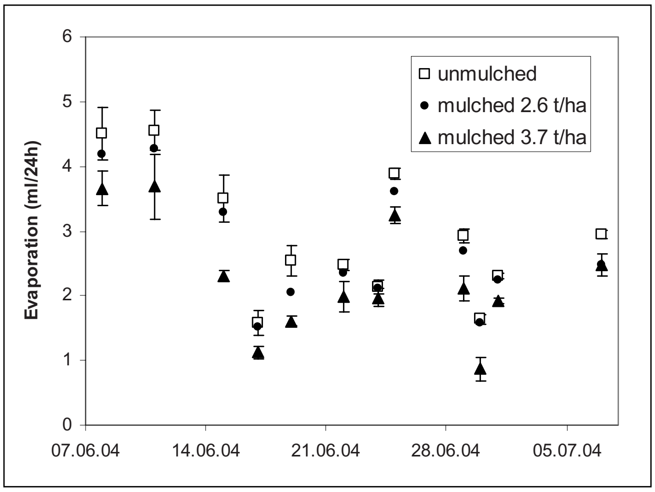

Fig. 3. Effect of straw mulch applied at different quantities on evaporation within the potato crop, experiment 19. Means (symbols) and standard errors (bars); for reasons of better readability SE bars are omitted from the treatment with lower mulch amount (2.6 t/ha).

Late blight

Late blight severity varied greatly between experiments, which was mainly due to the climatic conditions of the respective years. E.g, in the hot dry summer of 2003, late blight severity was very low. In all experiments, spatial effects on late blight were obvious, with significant block effects in experiments 1, 2 and 4 and 20.

Although mulching had no significant effect on late blight severity in the majority of the experiments, a consistent trend of reduced late blight was observed in 13 out of 15 experiments (Table 2). According to the DIXON and MOOD sign test, this trend was highly significant ($p < 0.01$). Regarding the relative area under the disease progress curve (RAUDPC), mulching showed a maximal reduction by 38.8 % in exp. 9 (median 6.4 %). While differences were not significant when comparing RAUDPC values, differences in DLA and incidence were significant in experiment 6, when disease was assessed relatively early in the season only. In order to test if this was a general trend, i.e. if a mulch effect would generally be observed early but would disappear over time, we conducted repeated measurement analyses over time. In these analyses however, there was no significant time by treatment effect, and we could not find any significant treatment effects in the early assessment dates.

In experiment 1, microclimatic measurements were done in the weeks before, during and after the onset of late blight infection. Here, the number of sampling times per day with conditions conducive to late blight (see above) was calculated for each day; then, the difference between mulched and unmulched plots was determined for this number and the difference was averaged per week. Following these calculations, mulching slightly reduced the late blight-conducive conditions two weeks and one week before 21 June 2002, when the first lesions were found (by 0.6 % and 1.8 %, respectively) but slightly increased it in the two following weeks (by 0.4 % and 0.8 %, respectively). We then analysed the cases when the microclimate was less conducive to late blight in the mulched plots and found that in the fortnight before the visible onset of infection the mulched plots were either „too dry“ (relative humidity < 90 %, during the day) or „too cold“ (air temperatures < 15 °C, during the night) for late blight infection.

Black scurf

There were no consistent effects of straw mulch application on the infestation of tubers with sclerotia of *R. solani* (Table 3). In 16 out of 17 experiments there were no significant differences between the infestation of tubers from mulched and unmulched plots, regarding both the disease severity index i_{Rs} and the percentage of uninfested tubers p_0. Also, there was no significant trend of differences. More heavily infested tubers from the mulched plots than from the unmulched plots, i. e., positive differences, were found in nine experiments and negative differences in eight experiments. There were no significant block effects, except for experiment 4 (parameter p_0).

Discussion

In summary, there was a clear tendency to a slight late blight reduction by straw mulch while the mulch application did not affect black scurf. Effects of straw mulch on air temperature and air humidity were small but pronounced in the period directly after mulching.

Generally, straw mulch is known to increase soil moisture by reduction of evaporation from the soil (RUSSEL, 1940). In the first few weeks after mulching this effect is likely to be responsible for lower air humidity and increased air temperature during day time. On the other hand, soil temperature during the night was shown to be higher under straw mulch than with unmulched soil (MUSSO, 1932), because the mulch layer acts as a heat isolator. Mulching decreased the absolute humidity during the night (data not presented). Therefore, the increase of relative humidity at night caused by mulching is mainly due to lower air temperatures, which also increase dew formation (JACKS et al., 1955, p. 22). However, also during the day the higher albedo of straw mulch than that of soil may lead to decreased surface and air temperatures, especially when the soil is dry. Therefore, the decreased evaporation from the vials in the mulched treatments in exp. 19 are not as surprising as the first view on the higher air temperatures in the straw mulched plots during the day (exp. 1) may suggest. Further possible reasons for reduced evaporation may include increased dew formation and lower temperatures during the night. In any case, because of the complex interactions between transpiration, air temperature, humidity, soil moisture and soil temperature, a comprehensvie explanation of straw mulch effects on microclimate requires further detailed measurements.

The spatial effects of late blight infections spreading from random foci may make it difficult to infer the reasons for the observations on late blight presented in this article. However, some speculations may be possible. Infections of *Phytophthora infestans* greatly depend on high humidity, so infections are more likely to take place during night than during day. However, the slightly moister and cooler nocturnal microclimate in mulched potatoes did not lead to higher disease severity. On the contrary, the overall trend was a disease reduction by mulching, although this effect was significant in only three experiments. The measurements in experiment 1 indicate that microclimatic conditions were less favourable for late blight infections at the onset of the infection.

The prevailing weather conditions in experiment 16 (frequent and heavy rains during summer) indicate that the interaction of straw mulch with rain splash dispersal of the pathogen could also be responsible for a possible reduction of disease severity. The variety used in this experiment (Christa) tends to „lay down“ more than the other varieties used (like, e.g., Nicola) that have a more upright plant architecture (BUNDESSORTENAMT, 2003); therefore, in more horizontally growing varieties like Christa rain splash dispersal may be of greater importance than in the other varieties. Straw mulch that is known to greatly reduce the impact of rain drops on the soil (BORST and WOODBURN, 1942) may have impeded rain splash dispersal of late blight in this case. Finally, differences in the plant nutritional status between mulched and unmulched plots may influence late blight severity. *Phytophthora infestans* is known to respond positively to the nitrogen content of the potato leaves (CARNEGIE and COLHOUN, 1983). Although at present there is no direct evidence for reduced nitrogen content in leaves of straw mulched potatoes, in two experiments 1 and 2, plants from straw mulched plots were assessed with Hydro-N-Tester (NEUKIRCHEN and LAMMEL, 2002). They were less dark green (more yellow) than from control plots (DÖRING et al., 2005), indicating a possible nitrogen-linked decrease in susceptibility to late blight. It was also observed in experiments 6 and 15 that leaf colour was more yellow in the mulched treatment or treatment with the highest amount of straw compared to the unmulched treatment. The strongest effects of straw mulch on late blight were observed in experiment 6. This is the experiment with the highest amount of straw applied, apart from experiment 12; however, late blight severity was very low in experiment 12 due to the hot and dry summer of 2003. Since effects of straw mulch on microclimate and rain splashing probably increase with increasing amount of straw applied, it may be concluded that the influence of straw mulch on late blight would have been clearer in the other experiments if a higher level of straw had been applied there too.

Although straw mulch is known to influence soil physical and chemical parameters and soil microbial populations (JACKS et al., 1955), it did not affect black scurf in our experiments. Black scurf is influenced by many parameters (e.g. see MÖLLER et al. 2003). Particularly, the pathogen benefits from organic matter incorporation from the pre-crop. In arable farms with a potato crop following winter cereals, it is not recommended to incorporate straw into the soil after wheat harvest, because the generalist fungus *R. solani* which survives on plant debris over winter may benefit from this practice and the risk is increased that emerging potatoes are infected by *R. solani* (MÖLLER et al., 2003, p. 116). For this reason, the application of straw mulch after the emergence of potatoes – instead of incorporating the straw into the soil before planting – is considered as a strategy for reconciling the aims of plant protection (regarding *R. solani*) and the closed cycle principle (regarding soil organic matter) (e.g., LAMPKIN, 1994).

The fact that straw mulch tended to reduce late blight and was neutral to black scurf in this study is seen as an important factor for the acceptance of this cultural technique.

Acknowledgements

We like to express our sincere thanks to G. KELLNER for excellent care of field experiments, U. BUSCH, V. JUNG, R. HEINKE, A. BOHL, P. URBATZKA, S. SIMON, S. POLREICH, L. HANS, S. LEISTNER, and S. VON LILIENFELD-TOAL for their help during assessments and following the harvest, and the farmers J. KEIL, C. MÜLLER-OELBKE, B. BARNSTORF-BRANDES and GRAF VON BASSEWITZ for their co-operation. We are grateful for the financial support of this study by the Bundesanstalt für Landwirtschaft und Ernährung (BLE, Bonn).

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Accepted: December 2005

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