Incorporation of organic broiler production in barley cultivation: the effects on crop performance and soil properties

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MSc Thesis

Master of Organic Agriculture

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Preface

The present study aimed to evaluate the effects of the broiler incorporation on crop performance and soil properties in organic barley cultivation, in the Netherlands. The research was conducted under the supervision of the Farming Systems Ecology group and is part of my MSc programme in Organic Agriculture at Wageningen University.

During this thesis research and the writing process I had the chance to learn not only on an educational but also on a personal level. I believe that this thesis constituted an opportunity for me to accumulate professional knowledge and experience in the research field that I am interested in and was a source of motivation for further development of my personality and personal achievements.

This work would have not been possible without the contribution of dedicated people. I am exceptionally grateful to my supervisors, Felix Bianchi and Jeroen Groot, who guided me throughout the whole thesis process with great patience and willingness to share their knowledge. I would also like to thank: Dine Volker, Andries Siepel and the staff of Unifarm-Agros for their assistance during the set up of the experiment and the data collection; and Hennie Halm for the laboratory analysis.

Finally, I would like to extend my gratitude to my family and friends (Eva, Yiannis, Dimitrios, Ivan, Myrto, Emmanouela and Andreas) who gave me support, motivation strength and encouragement to complete this study.

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Abstract

The intensive and specialized agricultural production systems and the increasing food demand pose challenges in the food security and the long-term sustainability of the agricultural systems. Thus, there is need of strategies which will promote the ecological processes and the biodiversity while ensuring sufficient production. There is a renewed interest in reintegrating crops and livestock which could foster diversity, utilize animal manure and consequently lead to higher yields. The current study aimed to unravel potential interactions, synergies and trade-offs of a fully combined crop-poultry system in barley cultivation. For this purpose, the interactive effects between two different broiler introduction dates (early vs. late) and the different distances from the hen house (1-11, 11-21, 21-31 or control) on the crop growth, soil properties and yield were assessed. Late introduction date resulted in about 13 ± 2.11 cm taller plants and an average increase of 58 % of the stem DW, compared to the early introduction date. The leaf DW, SLA and LAI did not differ significantly between the two broiler introduction dates, but after the broiler's introduction they decreased dramatically. Barley height, stem DW, leaf DW and leaf stem ratio were significantly lower, at both introduction dates, close to the hen house (1-11 m) than the control. Leaf stem ratio decreased dramatically in the plots where the broilers were released, compared to the control. Early introduction of broilers resulted in higher nutrient concentrations in barley stems and grains. In addition at the early introduction N, P and K concentrations, in stems and grains, were significant higher close to the hen house (1-11 m), compared to 11-21, 21-31 m from the hen house and the control. Regarding the soil properties, both introduction dates resulted in increased NH_4^+ at 0-5 cm as compared to the control, but NH_4^+at 5-30 cm increased only at the early introduction. However, the highest NO_3^- concentration at 0-5 and 5-30 cm was observed at the late introduction date at 1-11 m from the hen house. Available P and K at 0-5 and 5-30 cm were higher when the broilers were introduced early, with the highest K concentration at 1-11 m from the hen house. Yield experienced a significant decrease in the plots where the broilers were released (early introduction: 43%, late introduction: 39%), in comparison with the corresponding controls. However, the plots in which the broilers were introduced late led to significant increase of 27% in yield compared to those where the broilers were introduced early. Based on the results from the current study, it may be concluded that late introduction date resulted in better growth performance and yield, but early introduction resulted in higher plant nutrient uptake and lower residual nutrients in the soil. The integration of these findings and other key factors and variables that will be explored in the following studies might enhance our understanding of the intrinsic factors and processes governing a sustainable establishment of integrated crop-livestock systems.

1. Introduction

1.1. Background and Rationale

During the past half-century the intensive and specialized agricultural production has resulted in increased crop yields and consequently in a marked growth of food availability (Hilimire 2011; Xie et al. 2011). This achievement could be attributed to the use of chemical fertilizers and pesticides, the development of breeding methods and the improvements of cultivation techniques (Matson et al. 1997; Tilman et al. 2002; Khumairoh et al. 2012). However, concerns have been raised over the local and regional environmental consequences such as pollution, reduced soil fertility and biodiversity due to the long period application of chemicals and the degradation of the natural resources (Matson et al. 1997; Khumairoh et al. 2012). Moreover, the high costs of the intensifying agricultural systems, the continuing population growth and consequently the food demand, pose challenges in the food security and the long-term sustainability of the agricultural systems (Tilman et al. 2002; Godfray 2010; Xie et al. 2011).

Therefore, the future stability of the agro systems depends on strategies that will promote the ecological processes and the biodiversity while ensuring sufficient food. Under these challenges, the potential options to increase the long-term system sustainability by reducing the negative environmental effects and the dependency on external inputs could be based on an increasing complexity within the production systems (Khumairoh et al. 2012). This will aim to the better use and recycling of resources within the system (Schiere et al. 2001), the diversity (multi species agro systems) (Tilman et al. 1996; Vandermeer et al. 1998; Altieri 2002) and the re-integration of the livestock within the systems (Schiere et al. 2001; Ruselle et al. 2007, Hilimire 2011).

The role of the livestock in agricultural systems has been proved to be an essential component of the long-term sustainability due to closing nutrient cycles within the system. In mixed farming systems, the manure from the grazing land was used for crop production, closing a nutrient cycle on-farm and consequently enhancing the degree of self-sufficiency. Nevertheless, the land scarcity in some regions and the increasing demand for crop production instead of animal production result to the conversion of grazing land to arable lands (Schiere et al. 2001). Thus, it is very important that the agricultural strategies induce increased land-use efficiency. The incorporation of livestock into crop cultivation on the same piece of land in the context of multi-species agroecosystems provides sustainability in terms of better resource management (Vandermeer et al. 1998).

The integrated crop-livestock agriculture has been reconsidered the last years throughout the world as an alternative to specialized agriculture, which leads to environmental concerns and biodiversity loss. Hilimire (2011), based on a review among United States reported that the integration of livestock into crop cultivation leads to higher soil fertility, crop yields and biodiversity. In addition, the integrated system enhances the economic returns to farmers and provides social benefits to the community. However, it is highlighted that farmers willing to undertake crop /livestock agriculture could face challenges such as 'loss of animal husbandry knowledge', 'erosion of animal genetic diversity', 'regulations designed for specialized agro ecosystems' and 'limited meat processing infrastructure' (Hilimire 2011). Furthermore, after the analysis of integrated crop–livestock systems in North America, Russelle et al. (2007) concluded that farms which include livestock in the crop rotations with forages in grasslands have economic gains (higher production) and environmental benefits. The excreta are deposited directly in the grassland which later will accommodate the crops. Indeed, the utilization of the animal manure, improved the soil fertility by increasing the C sequestration, the soil organic matter and macronutrients. Carvalho et al. (2010) highlighted the significance of the incorporation of grazing animals into the crop rotation as an important modifier of the nutrient cycling dynamics. The positive effect of the rotational animal integration was reflected to the improved soil aggregation and soil microbial activity as well as the nutrients (NPK) availability.

Recently, there is an increasing interest in a specific type of integrated crop/livestock agriculture which is called fully combined (Hilimire 2011) and sometimes referred to as co-culture (Khumairoh et al. 2012). In this type of system, the animals are in the same piece of land, at the same time with the crops and graze underneath or between crops. Altieri (1999) also demonstrated that the diversity on-farm could be enhanced by the integration of crops and animals in the same piece of land. Such integration could develop complex interactions and synergies which contribute to the optimization of the ecological functions such as nutrient recycling, biomass production and accumulation, thus leading to increased soil fertility and productivity.

Experiments that conducted in China showed that the co-culture of rice and fish showed synergies in terms of biocontrol, reducing the need for pesticides (Xie et al. 2011). Moreover, the integration of compost, fish, ducks and azolla in the rice production system had also positive interactions by increasing the yield, the plant nutrient content, tillering and leaf area expansion (Khumairoh et al. 2012). However, the fully combined systems or the co-cultures have not yet been examined in other crops except for orchards and vineyards where the crops are high and there is no risk of crop damage. The main focus of the latter studies was to investigate the ability of ducks and free-range chickens to suppress weeds and pests (Ako and Tamaru 2006; Clark and Gage 1996; Clark and Gage 1997). Moreover, the integration of swine and poultry is proved to enhance the soil physical properties and decrease the weeds and pests (Hermansen et al. 2004). However, the potential synergies between the animals and main agricultural crops that will influence the crop growth and the soil fertility have not yet been investigated.

The importance of manure as a part of the organic fertilizers is well known. Indeed, manure includes partly digested and changed N and C from the plants, which contribute to soil organic matter maintenance and accumulation (Russelle et al. 2007). Bakry et al. (2009) reported positive effects of poultry manure in desert sandy soil in Egypt. They found that the manure contributed to higher maize yield as well as growth and grain quality variables (i.e. plant height, dry weight, contents of N, P and K). Nyakatawa et al. (2001) demonstrated that poultry manure enhanced soil fertility, the plant nutrient content and the crop yields. Poultry manure has been used in several crop cultivations due to the high nutrient content. Mahimairaja et al. (1995) reported that the poultry manure contains higher percentages of N, P in comparison with the cattle manure. The average values of broiler manure in Europe are 55-60% DM, 23-30 kg t^{-1} N_{total}, 19 kg t^{-1} P_2O_5 and 17 kg t^{-1} K_2O (Menzi et al. 1998). Hence, free-range chickens could be considered as part of a fully combined system (crops-animals) with perspective of higher soil fertility and final yields.

1.2. Thesis scope and objectives

Currently there is a need of knowledge regarding the effects of the incorporation of animals in organically managed crop production systems. A long-term study has therefore been initiated by Wageningen University in the Netherlands. This study aims to identify complex agro-ecosystems with potential benefits to sustainable agriculture. The premise of this research is that the use of the animals can reinforce the perceived benefits of their foraging behavior and the manure distribution. Barley is considered, after wheat and maize, one of the most important cereals in the arable crop production in the Netherlands, reaching 240.000 tons annually (FAO 2013). In the initial steps of this study, a field experiment was conducted to explore the effects of the incorporation of the broilers on crop performance and chemical soil properties in barley cultivation.

The overall objective of the current study was to investigate the effects of a fully-combined crop-poultry system on the crop growth, the final yield and the soil fertility in barley cultivation. In terms of a complex agro system, this study aims to explore the potential interactions, synergies and trade-offs of the proposed system. This study focused on the interactive effects between two different broiler introduction dates (early vs. late) and the different distances from the hen house (1-11, 11-21, 21-31 or control) on the overall crop performance and the soil chemical properties. The information obtained from the current study could be used for the future development of increased complexity within the agro systems.

Research Questions

What are the effects of the broiler introduction date and the distance from the hen house in an organic barley production system on the crop performance and the chemical soil properties?

a. What are the effects of the broiler introduction date and the distance from the hen house on crop growth variables, the plant nutrient content and the final yield?
b. What are the effects of the broiler introduction date and the distance from the hen on soil total and available N, P and K concentration and pH?

Hypotheses

It was hypothesized that the plant growth variables, plant nutrient content as well as the final yield would benefit from the incorporation of the broilers due to manure deposition. The crop performance, plant nutrient content and the final yield was expected to be higher in the early broiler introduction date due to better synchrony between the nutrient release and plant uptake in earlier growth stages. However, the crop damage from the broiler's foraging behavior was not taken into consideration because it was unpredictable. It was also hypothesized that the manure distribution would not be homogenous with the highest deposition to be close to the hen house. Thus, the N,P,K concentrations were expected to be higher close to the hen house (1-11 m) and decreasing with further distance at both broiler introduction dates. Finally, pH was expected to increase in the plots where the broilers were introduced due to manure decomposition.

2. Materials and Methods

2.1. Experimental Site conditions and weather

The field experiment was carried out during spring and summer of 2013 in the organic educational and experimental farm Droevendaal of Wageningen University (51°59'28.45"N, 5°39'29.50"E), Wageningen, the Netherlands. The preparations of the field started in late May, the experiment was set up in June and the final harvest of the barley took place in the mid-September. The mean annual temperature and annual precipitation were 11°C and 829 mm, respectively. The weather data (i.e. T_{min}, T_{max} and cumulative rainfall) during the experiment are shown in Fig. 1. The soil was classified as finely light loamy sand. Beginning from 2008 until 2012, the crop rotation included beans, barley, potatoes, triticale/grass clover and grass/clover.

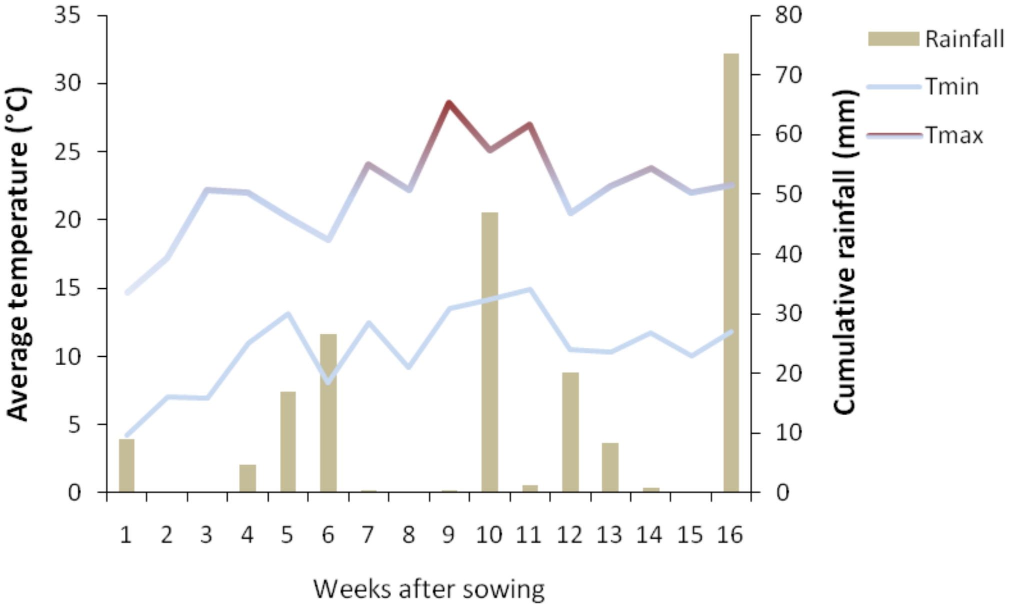


Fig. 1. Weekly weather data (Tmin, Tmax, Rainfall) during the barley cultivation period (16 weeks). The first week starts on 22 May (sowing week) and the last week ends on 10 September (harvest week).

2.2. Experimental design

The experiment was conducted under barley (*Hordeum vulgare* L. variety 'Shannon') cultivation in a fully-combined crop-poultry system. The experimental design was based on the broiler introduction date and the distance from the hen house, each of which included different levels as summarized in Table 1.

Table 1. Outline of experimental factors

Factors	Levels	
Broiler Introduction date	Early	
	Late	
Distance (m)	Close	(1-11 m)
	Middle	(11-21 m)
	Far	(21-31m)
	Control	(>31 m)

The field, of which the total size was 52 m x 25 m, was divided in four main sections (Fig. 2). The two sections were for the broiler's treatments and the other two represented the corresponding controls. The control treatments were separated in order the broilers not to have access on them.

The broiler ark (ARM Buildings Ltd) was placed in front of the sections that represented the broiler's treatments so that the broilers could be released in the two fields (Fig. 2). The dimensions of the mobile ark were 6.86 m × 2.74 m and it was separated in two compartments, one for each broiler treatment (Early, Late).

Mesh wire was used to separate the two sections (plots) of the broiler treatments (Early, Late) in order the groups of chickens not to be mixed. Each one of the two sections had dimensions of 25 m × 22.5 m and was divided into 25 sub-plots (5 m × 4.5 m each) in order to have a constant and comparable sampling scheme among the different measurements of the experiment. The lettering (A-E) and numbering (1-5) of the sub-plots was formed symmetrically regarding to the broiler house. The use of the combination of them indicated a specific sub-plot (Fig. 2). For every sub-plot the Euclidean distance from the hen house was calculated and the subplots were separated into the 3 different levels: 1-11 m, 11-21 m, 21-31 m distance from the hen house.

The third and fourth section of the field represented the control treatments (Early Control, Late Control) which had the highest distance from the hen house (>31 m) and the broilers did not have access. The size of every control plot was 27 m x 22.5 m. Every plot included 4 sub-plots, each of which had size of 6 m x 6 m and 3 m distance from each other (Fig. 2). The two different controls (Early Control, Late Control) indicated the different weed control time scene that was followed in the two broiler introduction dates (Table 2).

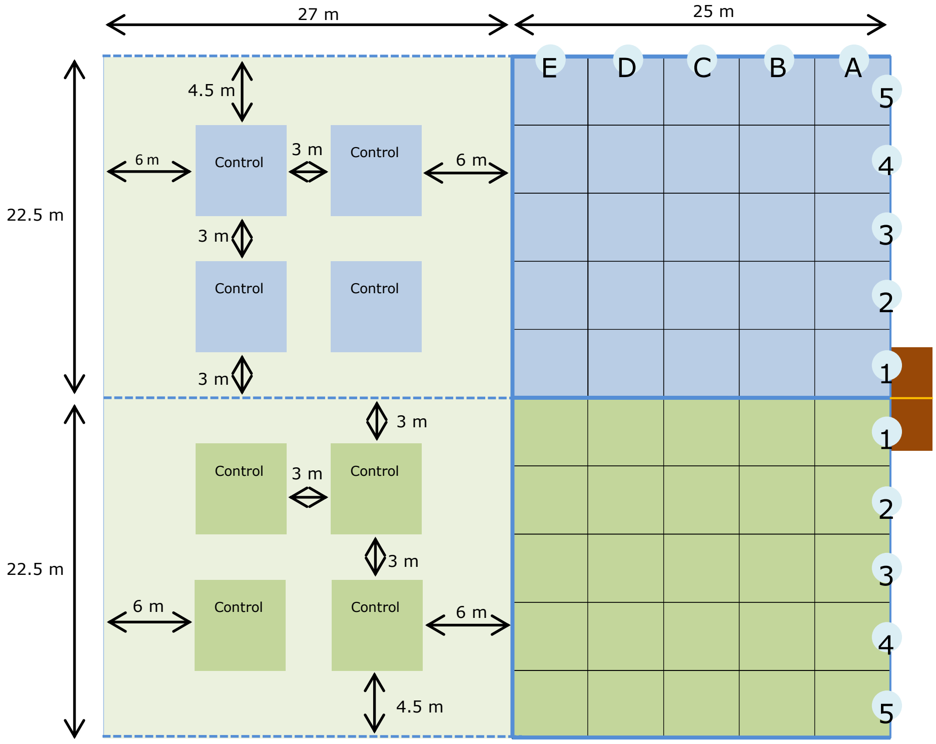


Fig. 2. Experimental layout on scale 1:500. The blue colour indicates the Early broiler introduction date. The green colour indicates the Late broiler introduction date.

2.3 Experimental management

2.3.1 Cultural practices

Barley seeds were planted at 5 cm depth with a 25 cm sowing spacing. Raw dairy manure (RDM) was applied in spring, two months before the establishment of the barley cultivation (84.24 kg N ha^{-1}, 36.48 kg P ha^{-1}, 182.4 kg K ha^{-1}). Standard organic tillage practices were entailed in the field, using a four furrow plough to a depth of 25 cm. Weed control was continued until one week before the broiler's introduction date for both the early and late treatment. Under drought conditions, from the 7th to 9th week after sowing (Fig.1), the field was irrigated 3 times with 20 mm water using pipes. Detailed data about the field operations can be found in Table 2.

Table 2. Outline of field operations (2013)

Operation	Date
RDM application	7th March
Tillage	20th May
Sowing	23rd May
Weeding Early introduction	18th June
Weeding Late introduction	10th July
Early broiler introduction-removal	26th June-19th August
Late broiler introduction-removal	17th July-9th September
Irrigation	19th July/21th July/24th July
Barley Harvest	12th September

2.3.2 Broiler management

The experiment accommodated in total 108 organic slow-growing broilers of the Hubbard strain JA 957; 55 for the early introduction date and 53 for the late introduction date. The two batches of broilers were incorporated into the experiment five weeks or eight weeks (Early or Late respectively) after sowing of barley and remained in the experiment until they were 81 days old in both treatments (Table 2). The broilers were housed in different compartments inside the mobile broiler ark (6 birds/m^2) so each group had access to only one section of the field (Fig. 2). The broilers were delivered when they had reached the age of 4 weeks and they were kept indoors 2 days for acclimatization. Afterwards, the outdoor access was from 8:30 to 21:30 on daily basis, while the broilers were kept inside during the night for safety reasons. The outdoor space provided them approximately with 10.5 m^2 each. Three sheds were placed, in both early and late introduction dates, serving as shade shelters, but also to encourage them to move across the field to achieve homogeneous distribution. The sub-plots, in which the sheds were placed, were the 5A, 3C and 1E (Fig. 2)

The feeding of the broilers was consisted of 40% organic whole grain spring wheat (*Triticum spp*., variety: Lavett) and 60% organic concentrates (95% organic ECO Vleeskuikmeel 2). The wheat was dispersed in the field every morning while the concentrates were provided at night inside the house in metal feeders. The diet of the broilers was defined as restricted diet, 80% *ad libitum*; hence the daily feed supply reached 80 % of the required intake, in order to motivate the broilers for outside foraging. The water was available inside the house as well as outside and was replaced every day.

2.4. Field and laboratory analyses

2.4.1. Plant growth variables and yield components

Crop performance measurements were undertaken at various times during the experiment to capture the dynamics of the crop growth. In order to cause as less disturbance as possible in the field, it was decided each one of the 25 sub-plots to be used twice during the whole experiment. Every 7 days, 5 sub-plots were selected randomly and a row of $0.5625m^2$ (0.75 m × 0.75 m) was harvested. Totally, 9 destructive harvests for each broiler introduction date were performed during the experiment. For the controls (early, late), the destructive harvests also involved cutting of one row of plants $0.5625m^2$ (0.75 m × 0.75 m) and were conducted every 14 days and every time in 2 out of 4 sub-plots. The selection of the sub-plots was conducted randomly every week between the numbers of the same letter sub-plots (Fig. 2) to have a representative sample regarding the distance from the broiler house (i.e. stratified sampling). For example, the first week destructive harvest was occurred in the subplots 2A, 5B, 1C, 3D, 4E.

In every destructive harvest 7 representative plants were used to estimate the growth variables. These variables included the plant height (cm), the fresh and the dry weight of leaves and stems and the leaf area (LA). Measurements for the plant growth variables for the early introduction date started the day that the broilers were released into the field (Day 0) and for the late introduction a week before the broilers released into the field (Day 13).

Plant height was measured from the beginning of the roots up to the top of the plant and then leaves and stems were separated. The fresh weight of the leaves and stems was measured separately and the leaves were used to measure the leaf area using the leaf area meter (LI3100, Li-Cor, Lincoln, NE, USA). Afterwards, the samples were dried at 105^0C for 24 hours in order to determine the dry weight of both the leaves and stems. From these measurements we were able to calculate: a) the dry matter of the leaves and stems b) the leaf: stem ratio c) the Leaf Area Index (LAI) (Leaf Area m^2/ ground area m^2) and d) Specific Leaf Area (LA / Leaf dry weight in $cm^2 g^{-1}$).

At the final harvest, an area of $0.5625m^2$ (0.75m × 0.75 m) was harvested from each of the 25 sub-plots for each broiler introduction date (Early, Late) to assess *yield* and *yield components.* For the control treatment, the same area was harvested from each one of the 4 sub-plots per introduction date. The fresh weight of the ears and stems was calculated while the number of ears per subplot was also counted. Afterwards, the ears were threshed in the machine (Combine) and the fresh weight of the grains per sub-plot was measured. Then, the samples were dried at 70^0C for 72 hours, since this is the standard procedure for nutrient content measurements to avoid nutrient losses. Then, the dry weight for stems and grains was measured and used for the estimation the grain yield (kg/ha). Finally, the samples were grinded through a 2mm sieve and transferred for nutrient content (NPK) laboratory analysis. The samples were digested with a mixture of H_2SO_4-Se and salicylic acid (Novozamsky et al. 1983).

2.4.2. Chemical soil analyses

Three times during the experiment, soil samples were taken from the field; the first two were taken to assess the general nutrient (NPK) status in the field before the broilers were introduced (Appendix I.) and the last one was taken after the removal of the broilers to assess their effect on the soil nutrient concentrations

The first soil samples were taken before the sowing of the crop (22.5.2013) and the second before the early broiler introduction date (25.6.2013). Both samplings were conducted with a soil gouge using a zigzag pattern at two depths i.e. 0-30 and 30-60 cm. throughout the whole field (52 m x 25 m). Ten cores for each soil layer were mixed into a composite soil sample. Then, sub-samples were taken and dried at 40 °C for 24 hours and passed through a 2 mm sieve. The third soil samples were taken in the end of the experiment after the removal of the broilers (16.09.2103). This time, the samples were taken from each one of the 25 subplots in both early and late introduction date plots and each one of the 8 subplots of the corresponding controls. Ten samples were collected from each of two different depths i.e. 0-5 cm and 5-30 cm.

Soil NO_3^- and $NH4^+$ were measured with the methods described in Houba et al. (1990) by extraction in 0.01m $CaCl_2$ and analyzed using a segmented-flow system (Technicon Auto-analyzer II, Dublin, Ireland). For the soil available P, the samples were extracted with 0.01 M $CaCl_2$ and analyzed spectrophotometrically using a segmented-flow system (Skalar Analytical BV. Breda, the Netherlands). For the soil available K, the samples were extracted with 0.01 M CaCl2, vaporized and analyzed by flame emission spectrophotometer at a wave length of 766.5 nm. Total N and P contents were determined using the Dumas Method with a CHN1110 Element 142 Analyzer (CE instruments, Milan, Italy).

The first and the last soil samples were also used to measure the pH. The procedure included 0.01 M $CaCl_2$ extraction using a pH/mV meter and combined electrode (Inolab pH/ Cond Level 1, 25 ^oC, WTW).

2.5 Statistical analyses

Statistical analyses were conducted using the general linear models procedure in SPSS Statistics 17.0 edition (2008). All variables were checked for normality (Kolmogorov–Smirnov test) and homogeneity of variance (Levene's test). P stem, P grain and NH_4^+ 5-30 cm were log-transformed because the data did not meet the normality requirements. Analysis of variance (ANOVA) was performed for the chemical soil properties variables and yield components to determine statistical significance ($p < 0.05$) using a statistical model that included the factors Introduction and Distance as well as their interaction. For the crop performance variables analysis the mixed effect model was used, in which the Introduction and Distance were placed as fixed factors and the time as a random factor. Mixed effect was chosen in this situation, taking into consideration its ability to handle correlated data (i.e. repeated measurements) and unequal variances (McCulloch & Searle, 2000). Differences between means for all the variables were analyzed by a post-hoc Scheffé test for multiple comparisons. When interaction between the factors was found to be significant a test of simple main effects was conducted (Bonferroni test). Finally, MATLAB 8.0/Statistics Toolbox 8.1 was used to visualize the spatial distribution of yield in the field.

3. Results

3.1 Crop performance

3.1.1 Plant growth variables

Height

Plant height data revealed a significant interaction between the introduction date and time ($p<0.05$) (Fig. 3a). Late introduction resulted in about 13 ± 2.11 cm taller plants compared to the early introduction during the whole period ($p<0.05$). However, plant height in both treatments followed a fairly similar pattern over time, except for the sharper decline which was observed in early introduction after day 41 (Fig. 3a). In addition, plant height close to the hen house (1-11 m) was observed to be significantly lower ($p<0.05$), than at 11-21, 21-31 m and the control. However, no significant difference among the other distances (11-21, 21-31 m) and the control was found (Fig. 4).

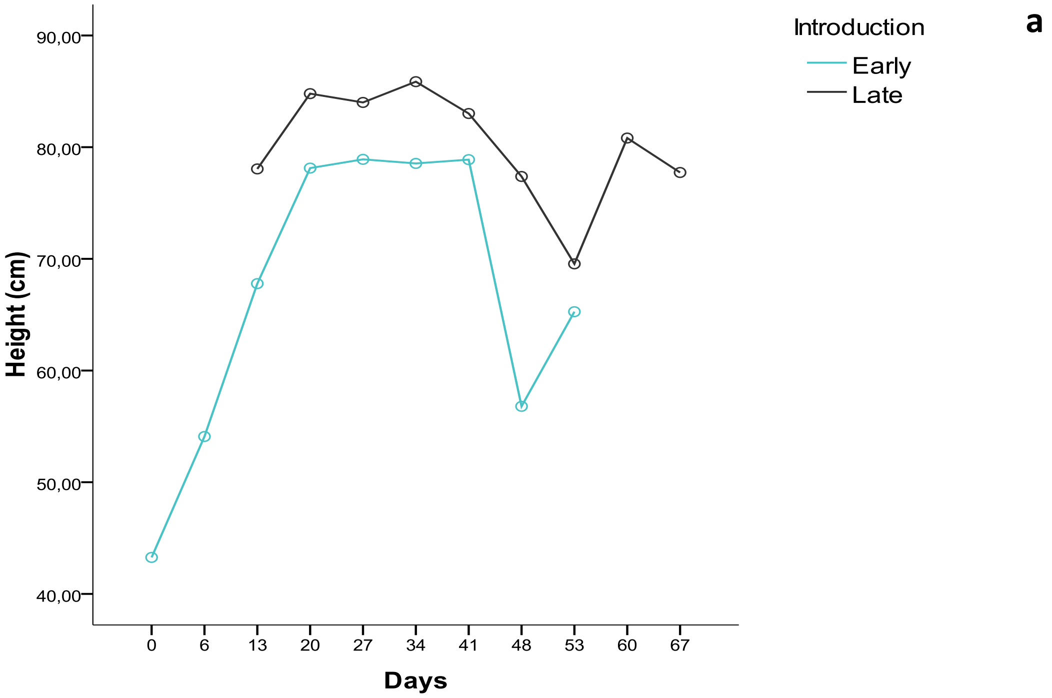


Fig. 3a. Development of barley height (cm) for early vs. late broiler introduction date.

Stem dry weight (DW)

There was a significant effect of introduction date and distance from the hen house on stem DW (Fig.3b & Fig.4). Stem DW was higher at the late introduction in comparison with the early introduction (39.3 and 24.9 respectively) ($p<0.05$). However, stem DW in both treatments showed similar trend during time with the early introduction having a steeper decline after day 41 than the late (Fig. 3b). Moreover, stem DW close to the hen house was significantly ($p<0.001$) lower (22.4) than the control (45.2). Stem DW at 11-21 and 21-31 m was significant lower than the control but still higher than at 1-11 m (Fig. 4).

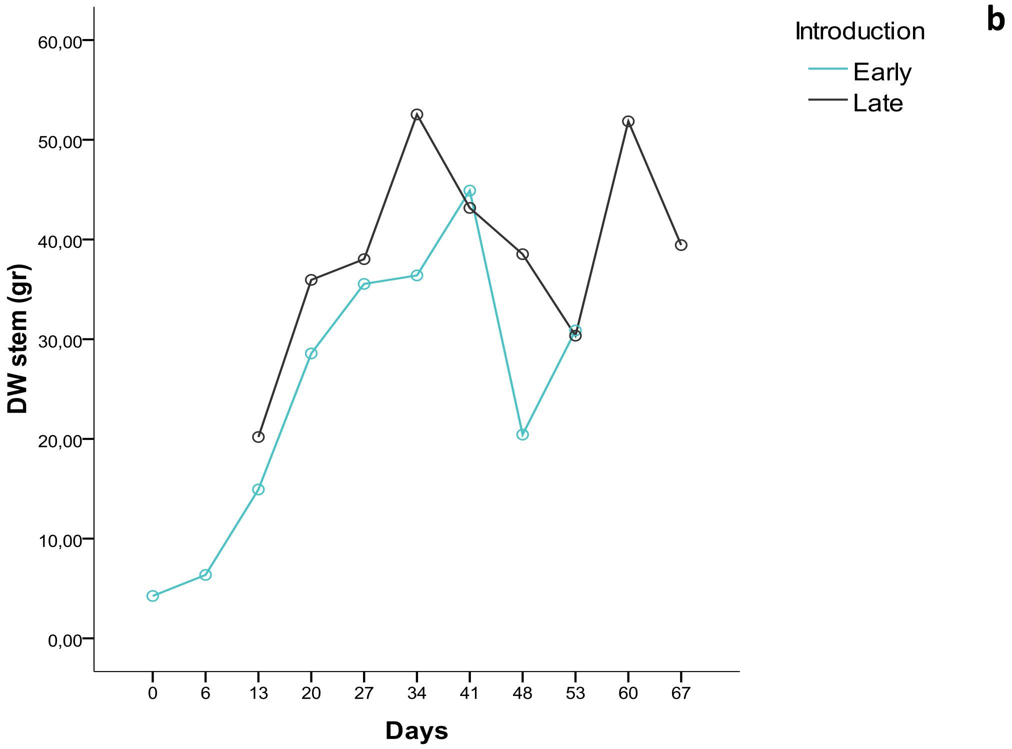


Fig. 3b. Development of barley stem dry weight (gr) for early vs. late broiler introduction date.

Leaf dry weight (DW)

Leaf DW was not significantly affected by the introduction date, although the values tended to be higher in late introduction (Fig. 3c). However, leaf DW were affected by the distance from the hen house ($p<0.05$), with the DW leaf of the control plots being significantly higher than at all the other distances (1-11, 11-21, 21-31 m) (Fig. 4).

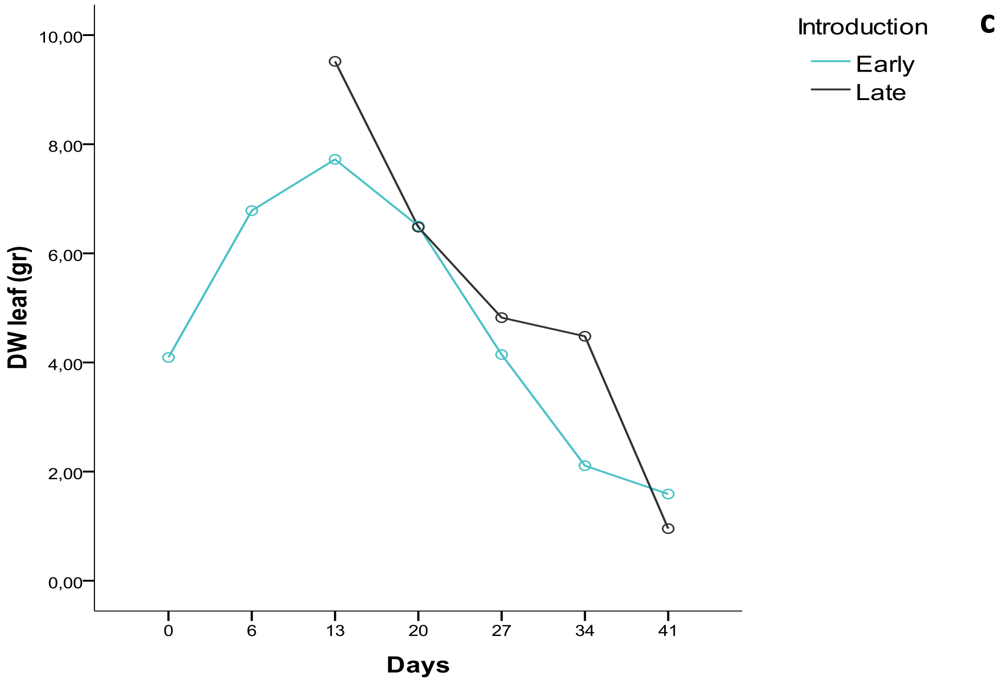


Fig. 3c. Development of barley leaf dry weight (gr) for early vs. late broiler introduction date.

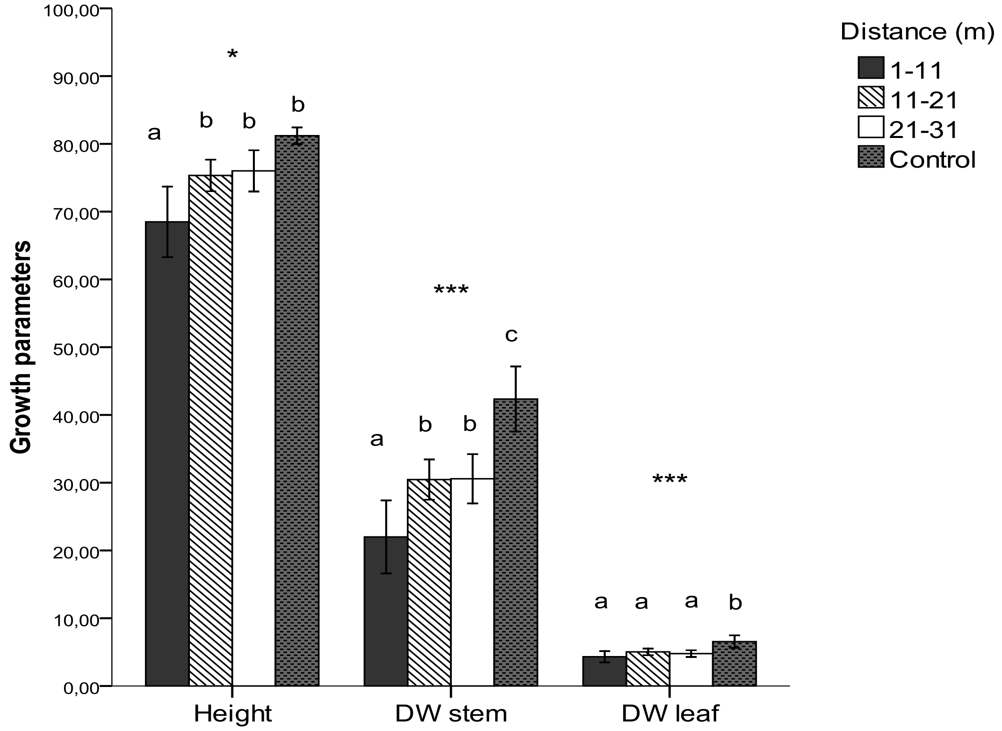


Fig. 4. Barley height (cm), stem dry weight (gr) and leaf dry weight (gr) at different distances from the hen house (1-11, 11-21, 21-31 m or control). The bars represent the standard error of the means. Bars with different letter differ significantly. Coding: n.s: not significant, *, **, ***, significant at p<0.05, <0.01, <0.001 respectively.

Leaf stem ratio

There was a significant interaction between the distance and time on the leaf stem ratio (p<0.05). Leaf stem ratio, at all three distances (1-11, 11-21, 21-31m), followed similar trend over time by declining very rapidly, whereas the control had a steady decrease during time. Furthermore, leaf stem ratio at the control plots was significantly higher in comparison with the other three distances (1-11, 11-21, 21-31m) (Fig. 3d)

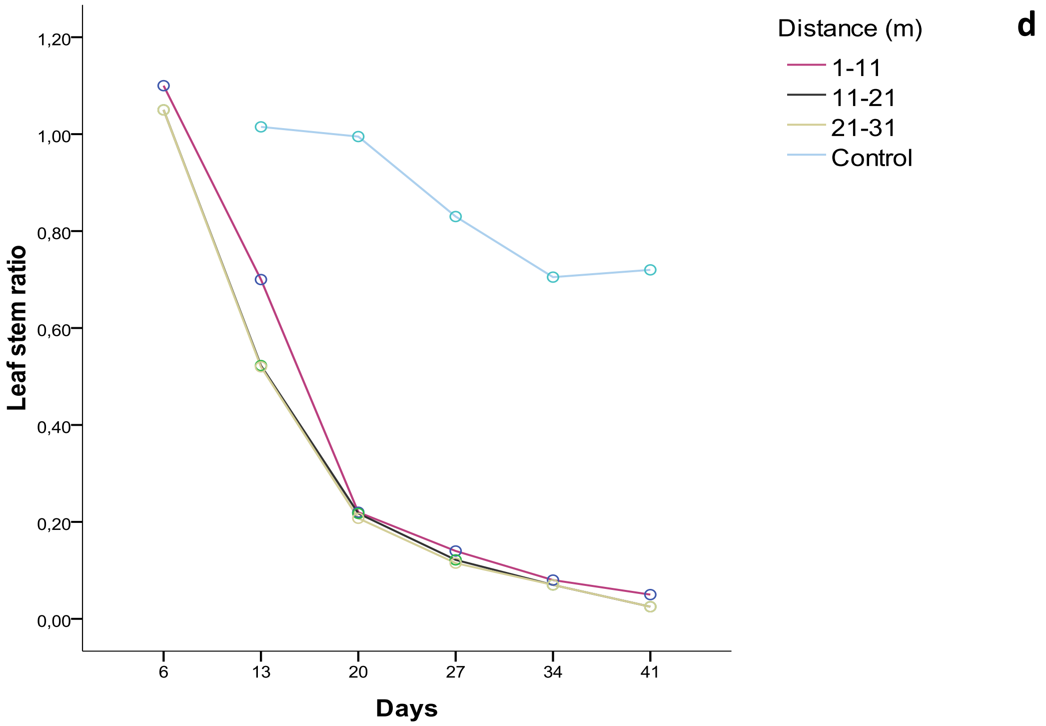


Fig. 3d. Development of barley leaf stem ratio at different distances from the hen house (1-11, 11-21, 21-31 m or control).

SLA-LAI

SLA and LAI showed similar dynamics during time with a dramatic decrease in values starting after day 13 but smoothening during time. There was no significant effect of introduction date and distance from the hen house, although both SLA and LAI tended to be higher in late introduction treatment (Fig.3e & Fig.3f).

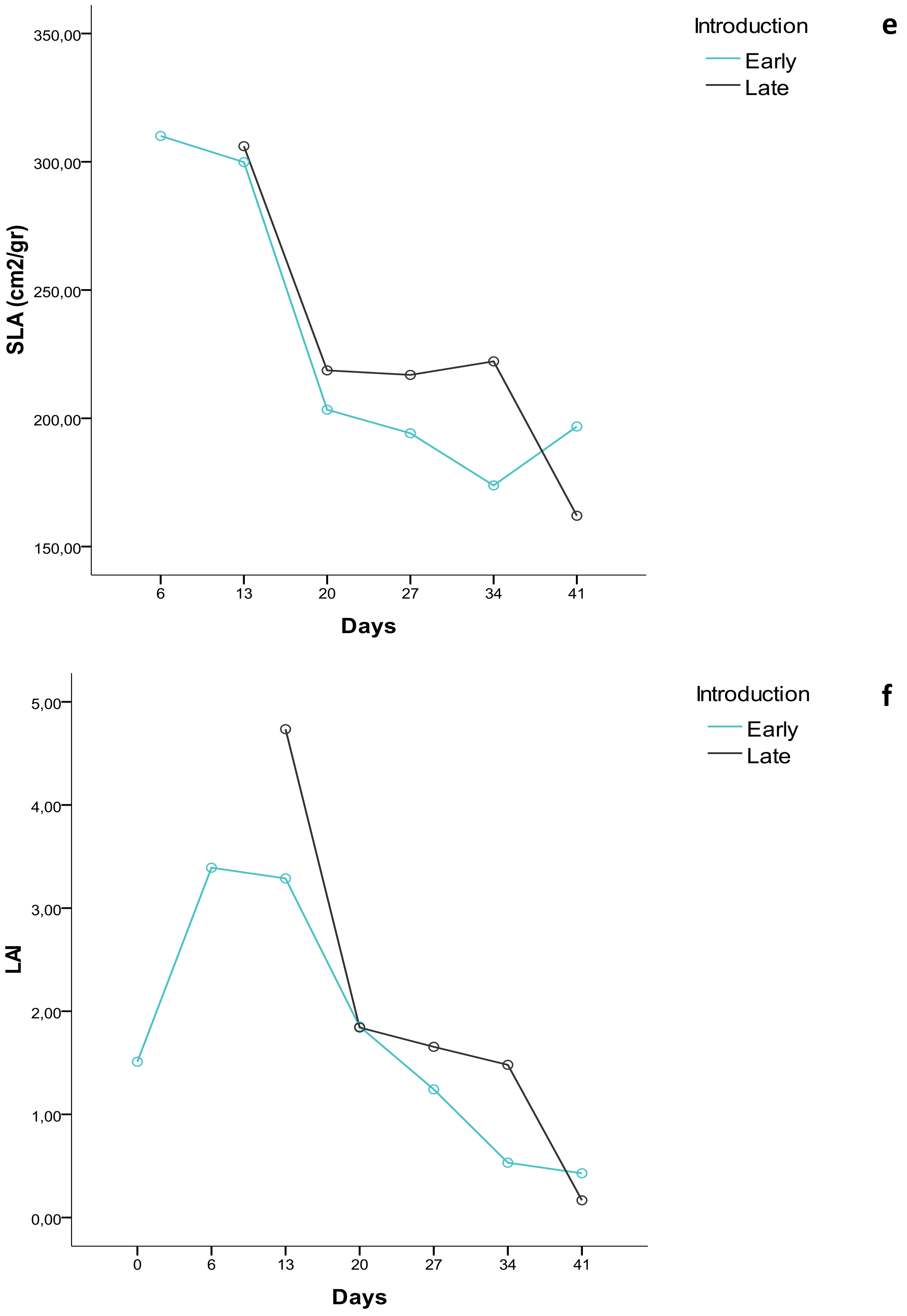
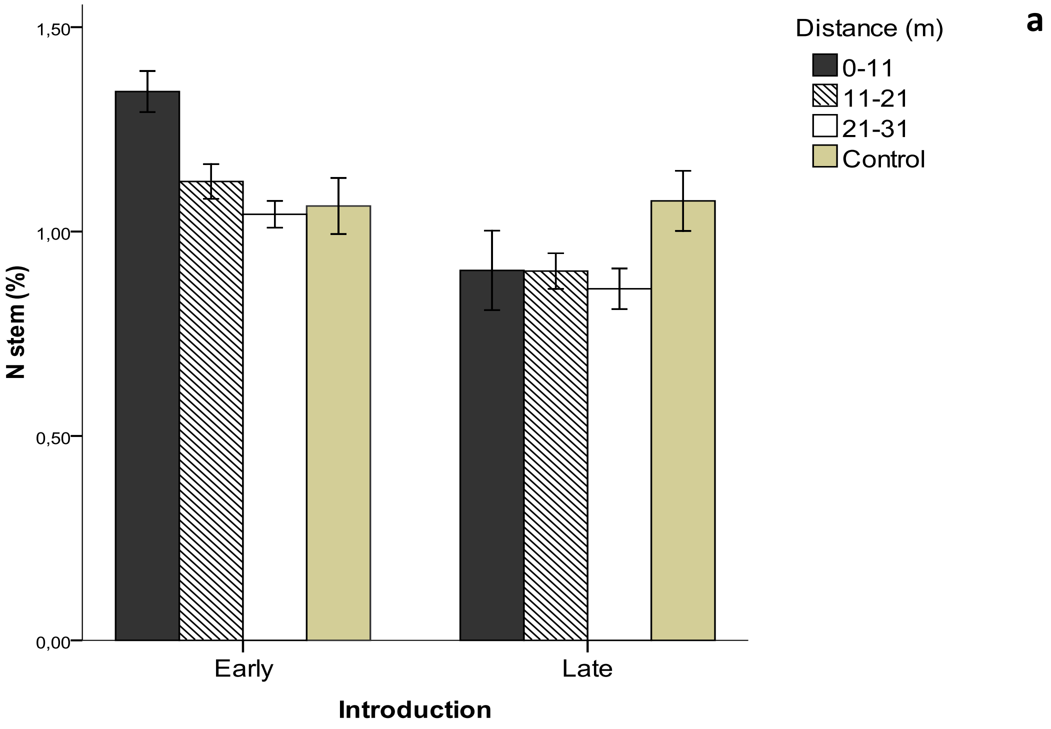


Fig. 3e,f. Development of barley SLA (cm^2 gr $^{-1}$) and LAI for early vs. late broiler introduction date.

3.1.2. Plant nutrient content

a) Nutrient concentration in stems of nitrogen (N) and phosphorus (P) showed that they were significantly influenced by the interaction between the introduction date and the distance from the hen house ($p<0.05$ and $p<0.001$ respectively). In the early introduction date, N, P, K concentrations were observed to have a significant upward shift in comparison with the late introduction date (Fig. 5a,b,c). Plants close to the hen house (1-11 m) had significantly higher N and P concentrations (1.35% and 0.17%, respectively), than plants at 11-21, 21-31 m and the control plots (≈1 % N and ≈0.1 % P, respectively). Both N and P concentrations were significantly decreased with further distance from the hen house (11-21> 21-31> control) (Fig. 5a & Fig. 5b). In contrast, in late introduction date, N and P concentrations at all the distances (1-11, 11-21, 21-31 m) were not significant different from the control, but were significant lower than those at the early introduction date. Finally, K concentration was significantly affected only by the introduction date ($p<0.001$), with the percentage of the early introduction being almost twice as high as of the late introduction date (Fig. 5c).



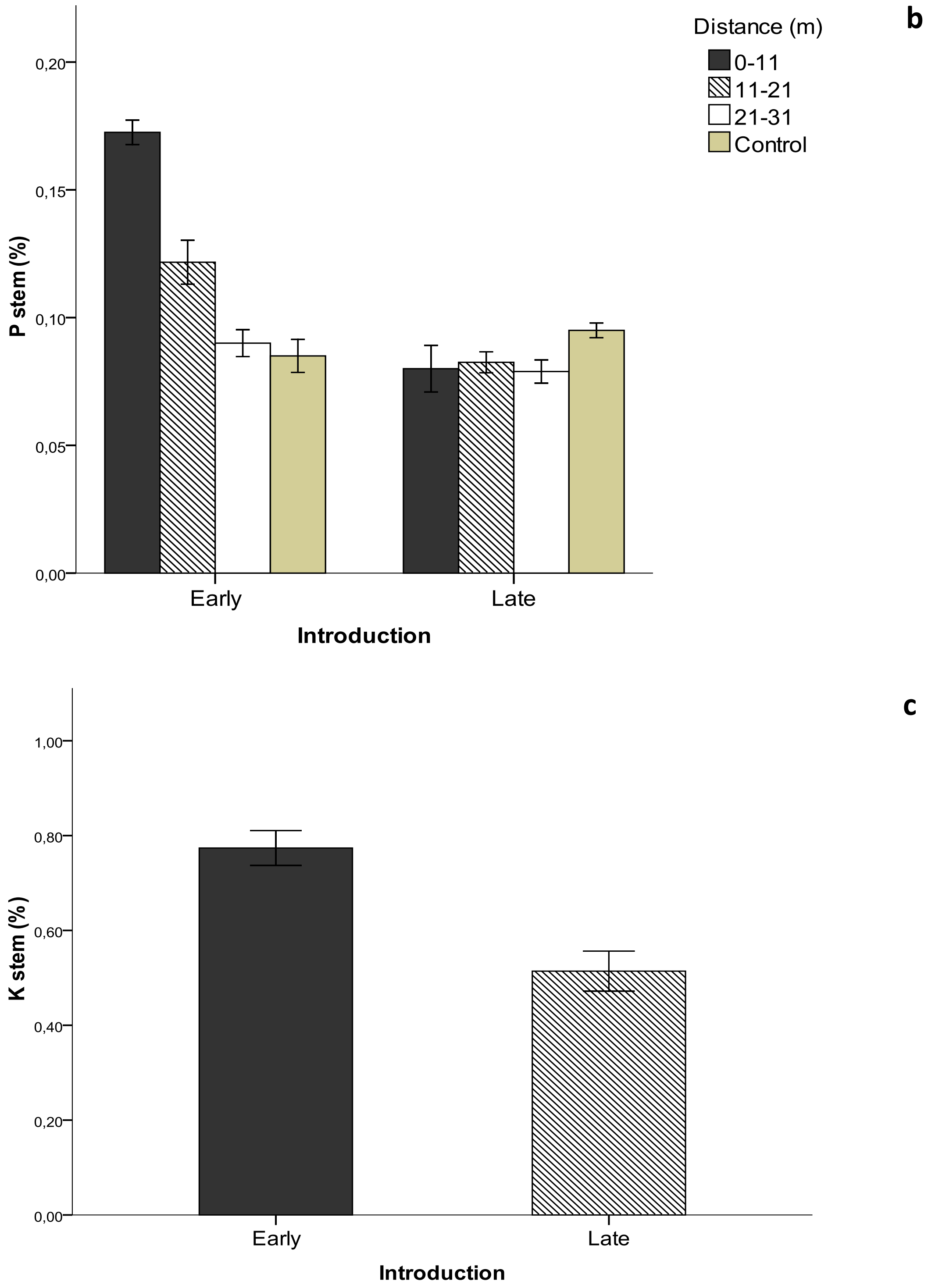
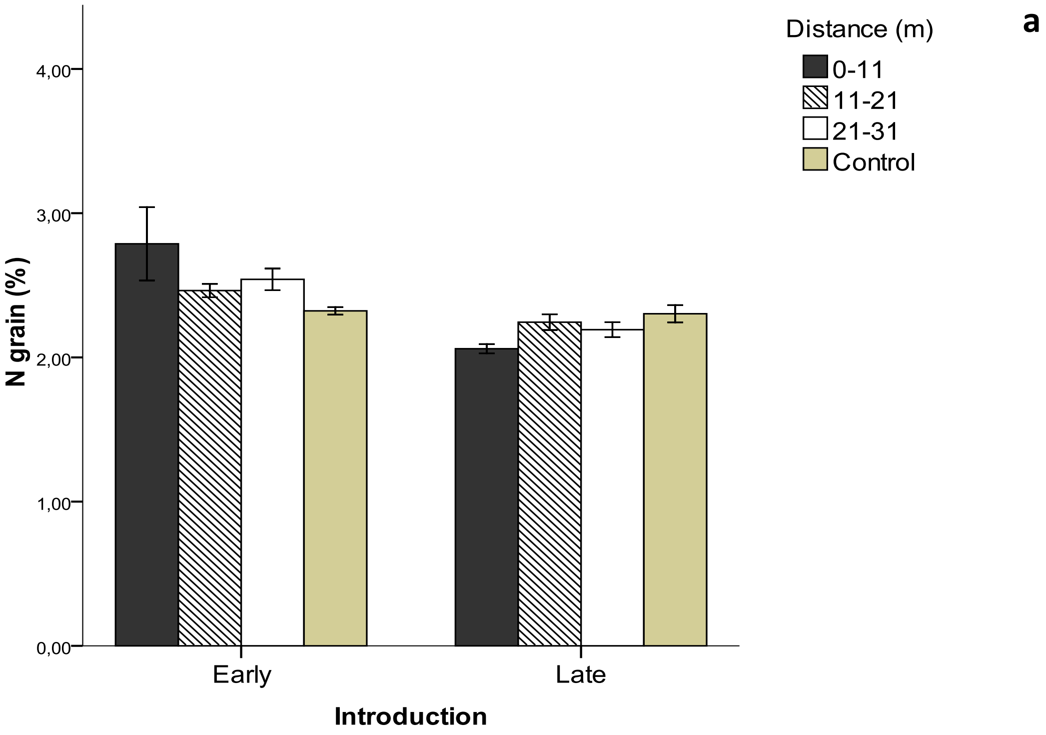


Fig. 5 a,b,c. Nitrogen, phosphorus and potassium concentrations (%) in stems of barley for early vs. late broiler introduction date at different distances from the hen house (1-11, 11-21, 21-31 m or control) at final harvest. The bars represent the standard error of the means.

b) Nutrient concentration in grains of nitrogen (N), phosphorus (P) and potassium (K) revealed a significant interaction between the introduction date and the distance from the hen house (p<0.05, p<0.001, p<0.001 respectively). Early introduction date resulted in significantly higher N concentrations, at all the distances (1-11, 11-21, 21-31 m), compared to the late introduction date (Fig. 6a). In the early introduction date, plants close to the hen house (1-11 m) had significant higher N, P, K concentrations (2.81%, 0.54%, and 0.59%, respectively), than plants at 11-21, 21-31 m and the control plots. (Fig. 6a,b,c). In contrast, in the late introduction date distance did not affect the N and P concentrations, whereas the distance close to the hen house (1-11 m) resulted in the lowest K concentration (0.47%). Plants at 11-21, 21-31 m had significantly higher K concentration, compared to those at 1-11 m and the control plots (Fig. 6c).



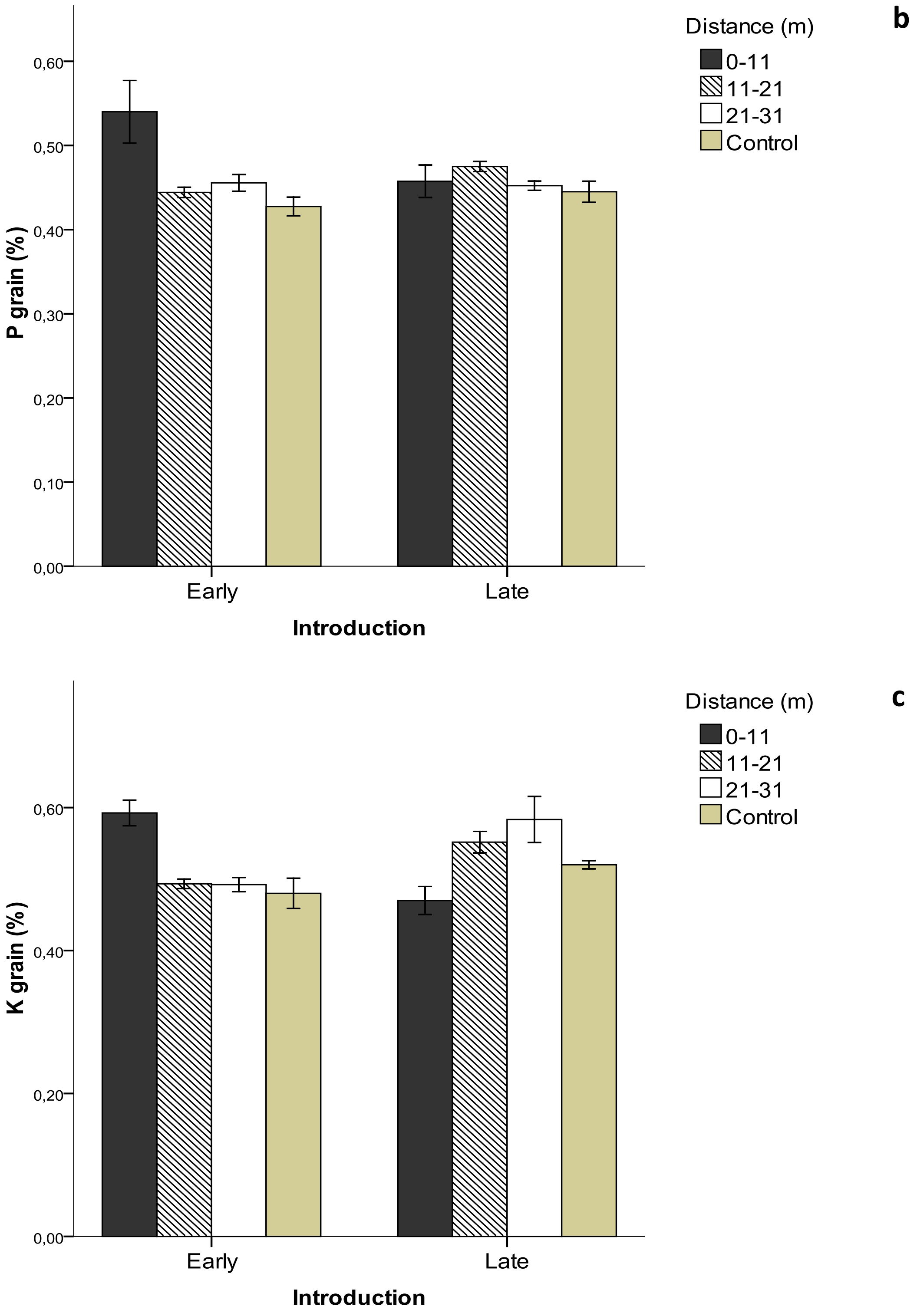


Fig. 6 a,b,c. Nitrogen, phosphorus and potassium concentrations (%) in grains of barley for early vs. late broiler introduction date at different distances from the hen house (1-11, 11-21, 21-31 m or control) at final harvest. The bars represent the standard error of the means.

3.2 Chemical soil properties

3.2.1 Soil total N and P

The concentration of soil total N (%) at 0-5 cm and P (%) at 5-30 cm was not found to be significantly affected by the introduction date or the distance from the hen house. In contrast, concentration of P (%) at 0-5 cm increased by 6.2 % in early introduction date (Table 3).

Table 3. Influence of the broiler introduction date (Early vs. Late) and distance from hen house (1-11, 11-21, 21-31 or control) on soil total N and total P (%) at 0-5 cm and 5-30 cm at final harvest of barley.

	0-5cm		5-30cm	
	N%	P%	N%	P%
Introduction (I)				
Early	0.099	0.068	0.101	0.066
Late	0.102	0.064	0.104	0.066
Significance	ns	**	ns	ns
Distance (D)[2]				
1-11 m	0.095	0.066	0.096	0.067
11-21 m	0.102	0.065	0.102	0.065
21-31 m	0.103	0.068	0.104	0.067
Control	0.103	0.065	0.107	0.065
Significance	ns	ns	*	ns
I×D	ns	ns	*	ns

[1] *, ** and *** refer to *P* values < 0.05, < 0.01 and < 0.001, respectively; ns = not significant.

[2] No mean separation for main effects is presented whether the interaction effect was significant (*P* < 0.05); Different letters indicate significant differences according to Scheffé test (*P* < 0.05).

The N (%) concentration data at 5-30 cm revealed a significant interaction (p<0.05) between the introduction date and the distance from the hen house (Table 3). Late introduction date increased the N concentration at 11-21 m from the hen house, compared to the early introduction date (Fig.7). In the late introduction date, the distance did not affect the N concentration, while in the early introduction N concentration was significant lower at 1-11 and 11-21 m, than at the control (Fig. 7).

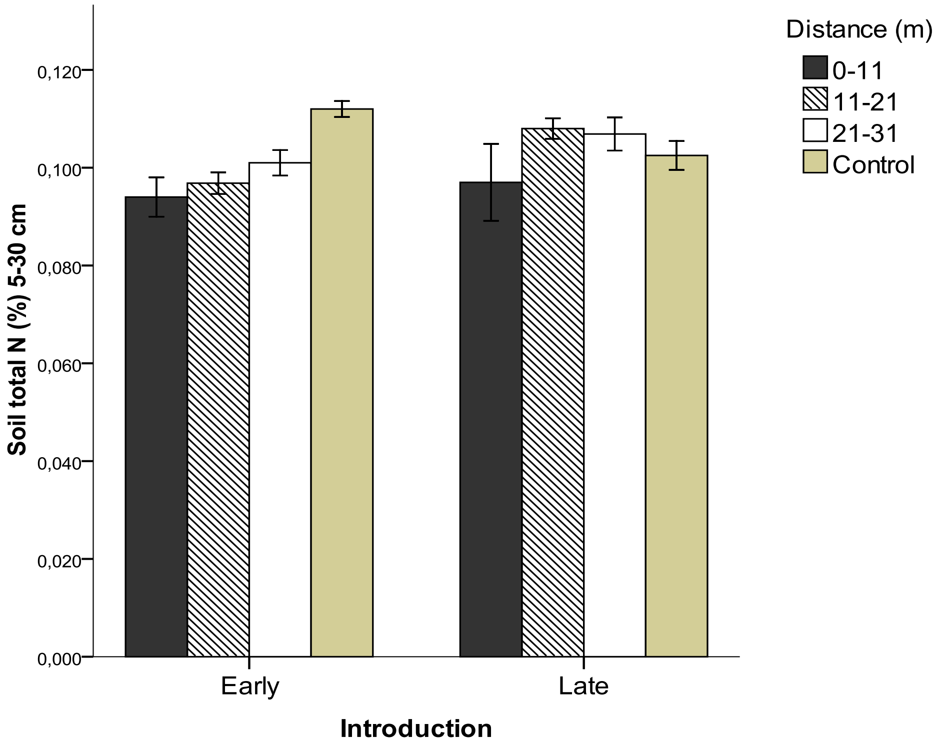


Fig. 7. Total soil nitrogen concentration (%) for early vs. late broiler introduction date at different distances from the hen house (1-11, 11-21, 21-31 m or control) at final harvest of barley. The bars represent the standard error of the means.

3.2.2 Soil available NPK

There was a significant interaction between the introduction date and distance from the hen house on NH_4^+, NO_3^-, PO_4 and K at 0-5 cm and only for NH_4^+, NO_3^- at 5-30 cm. $PO_{4,}$ at 5-30 cm, was affected only by the distance, with the control being significantly higher than all the other distances from the hen house. K, at 5-30 cm, was significantly higher at the early introduction date, than at the late (Table 4).

Table 4. Influence of the broiler introduction date (Early vs. Late) and distance from hen house (1-11, 11-21, 21-31 or control) on soil NH_4^+, NO_3^- , PO_4 and K (mg kg^{-1}) at 0-5 cm and 5-30 cm at final harvest of barley.

	0-5cm				5-30cm			
	NH_4^+	NO_3^-	PO_4	K	NH_4^+	NO_3^-	PO_4	K
	mg kg^{-1}							
Introduction (I)								
Early	6.030	3.818	0.830	62.564	5.726	2.590	0.939	63.284
Late	6.285	5.410	0.672	28.140	3.384	4.285	0.867	25.920
Significance	ns	*	***	***	ns	***	ns	***
Distance (D)[2]								
1-11 m	8.575	6.581	0.762	54.451	3.313	3.600	0.888 b	54.296
11-21 m	5.865	4.302	0.779	39.923	5.306	3.987	1.088 b	41.306
21-31 m	6.142	3.422	0.750	36.283	5.539	3.350	0.961 b	36.294
Control	4.050	4.150	0.712	50.750	4.062	2.812	0.675 a	46.513
Significance	ns	ns	ns	***	ns	ns	***	ns
I×D	***	**	**	**	**	**	ns	ns

[1] *, ** and *** refer to *P* values < 0.05, < 0.01 and < 0.001, respectively; ns = not significant.

[2] No mean separation for main effects is presented whether the interaction effect was significant (*P* < 0.05); Different letters indicate significant differences according to Scheffé test (*P* < 0.05).

In the upper soil layer (0-5 cm), the late introduction date at 1-11 m from the hen house resulted in a pronounced increase of NH_4^+ compared to early introduction date, but also in comparison with the other distances (11-21, 21-31 m). In contrast, for the lower layer (5-30 cm), early introduction resulted in higher NH_4^+ at 11-21, 21-31 m compared to late introduction (Fig. 8a).

Similarly, NO_3^- values close to the hen house (1-11 m) were the highest at the late introduction date at both soil layers. These values were significant higher compared to 11-21, 21-31 m and the control, while in the early introduction date no difference in means occurred (Fig. 8b).

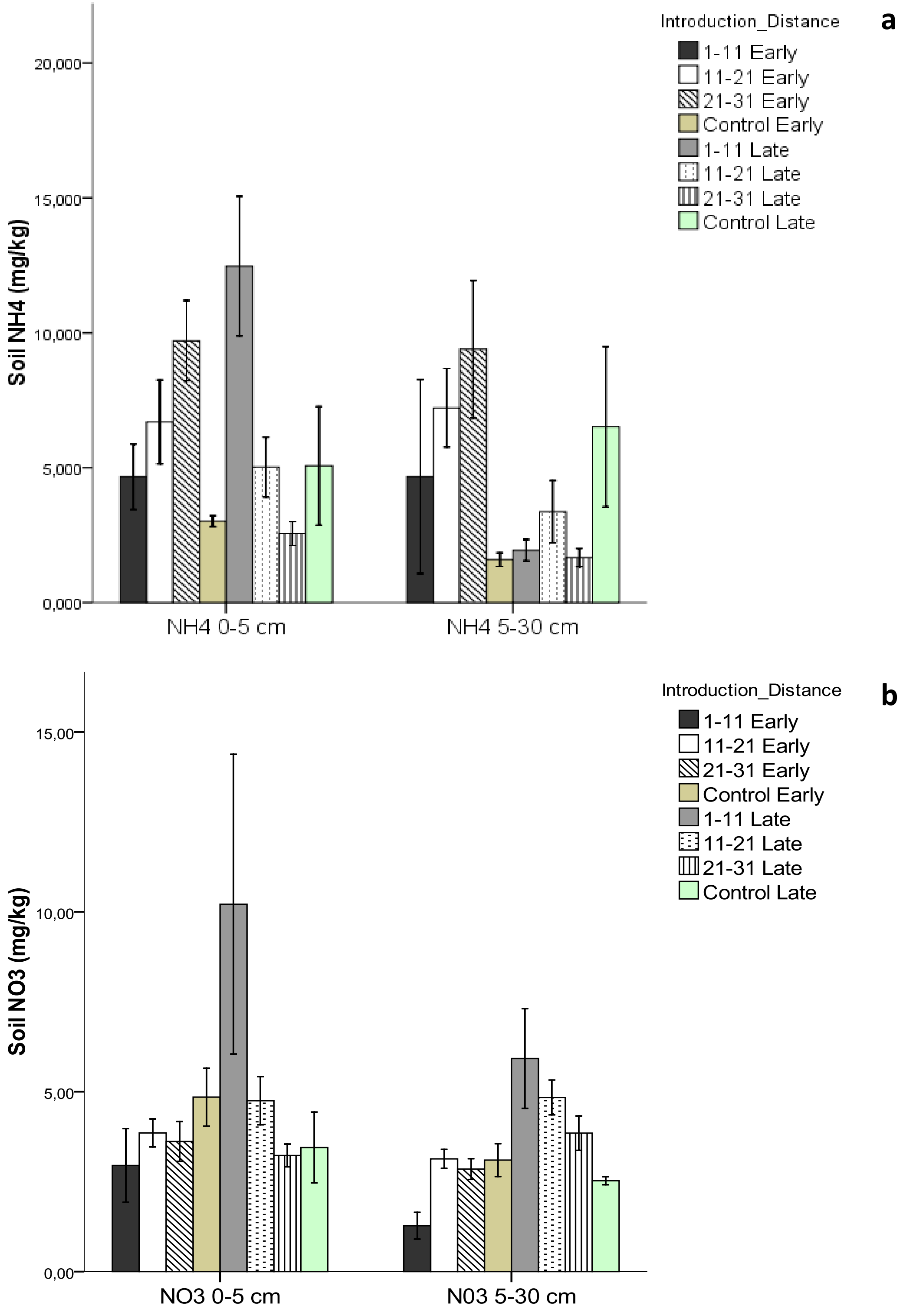
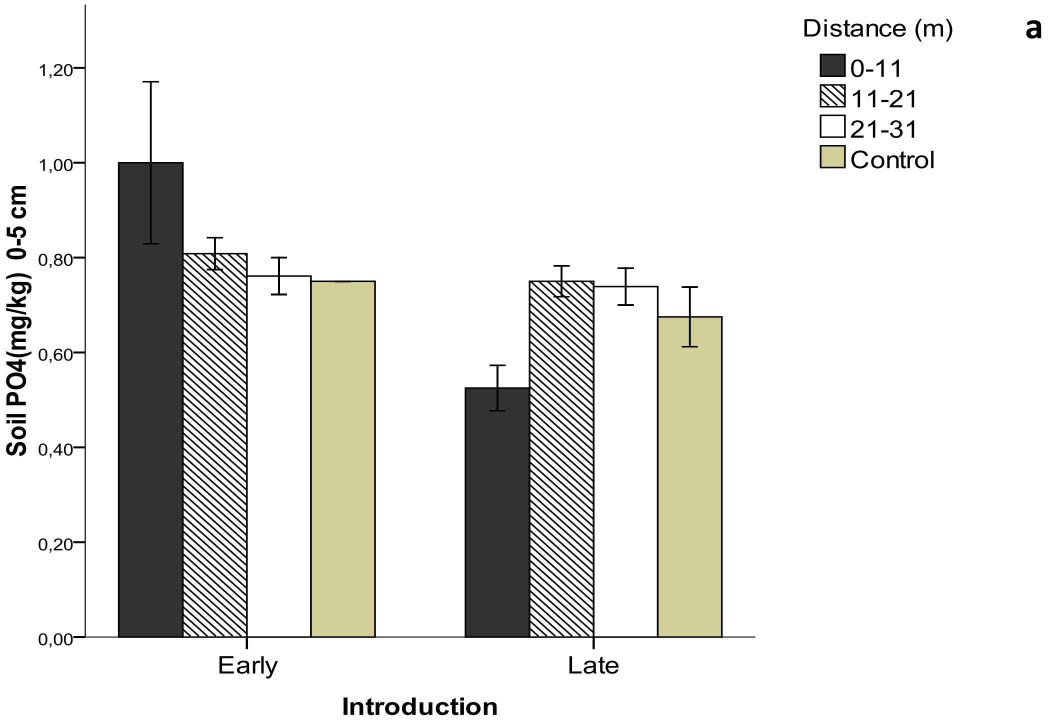


Fig. 8 a,b. Soil NH_4^+, NO_3^- (mg kg^{-1}) at 0-5 cm and 5-30 cm for early vs. late broiler introduction date at different distances from the hen house (1-11, 11-21, 21-31 m or control) at final harvest of barley. The bars represent the standard error of the means.

Based on the trend of soil PO_4 at 0-5cm, it appears that the distance effect was remarkable at 1-11 m with early introduction date leading to increased PO_4 concentration, whereas significant lower concentration at the same distance was found in the late introduction (Fig. 9a).

Concentration of K at 0-5 cm was affected by the introduction date with an upward shift of the early introduction at all the different distances in comparison with the late introduction date. In the early introduction, the highest K concentration was observed at 1-11 m from the hen house, while in the late introduction no differences among the distances and the control occurred (Fig. 9b).



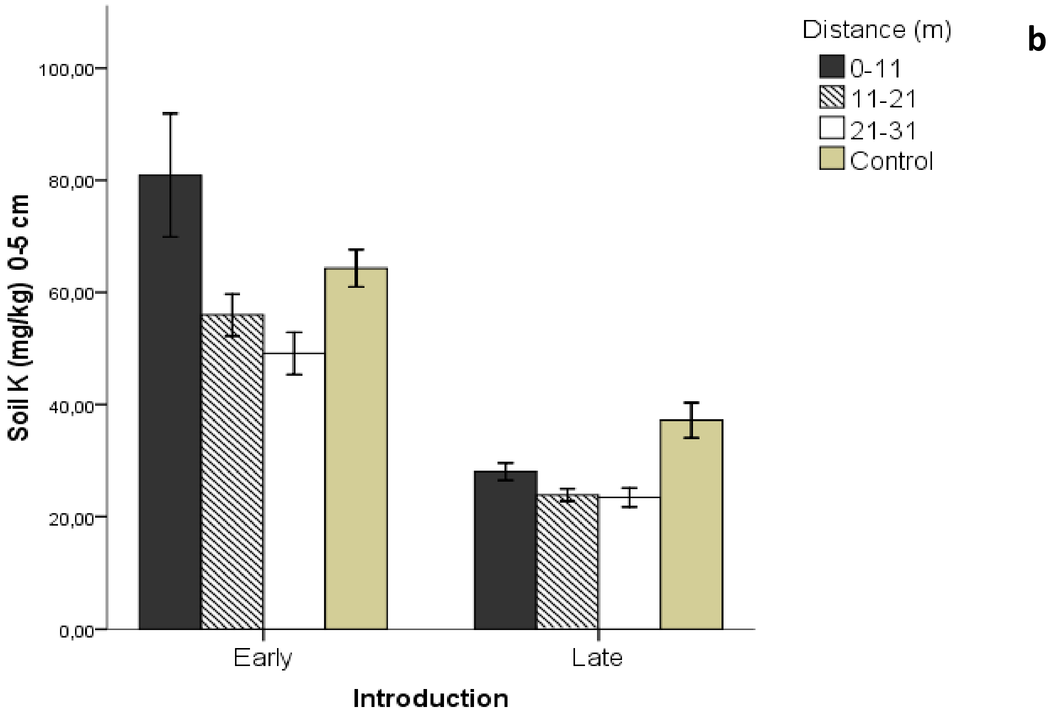


Fig. 9 a,b. Soil PO_4 and K (mg kg^{-1}) at 0-5 cm for early vs. late broiler introduction date at different distances from the hen house (1-11, 11-21, 21-31 m or control) at final harvest of barley. The bars represent the standard error of the means.

3.3 Yield and yield components

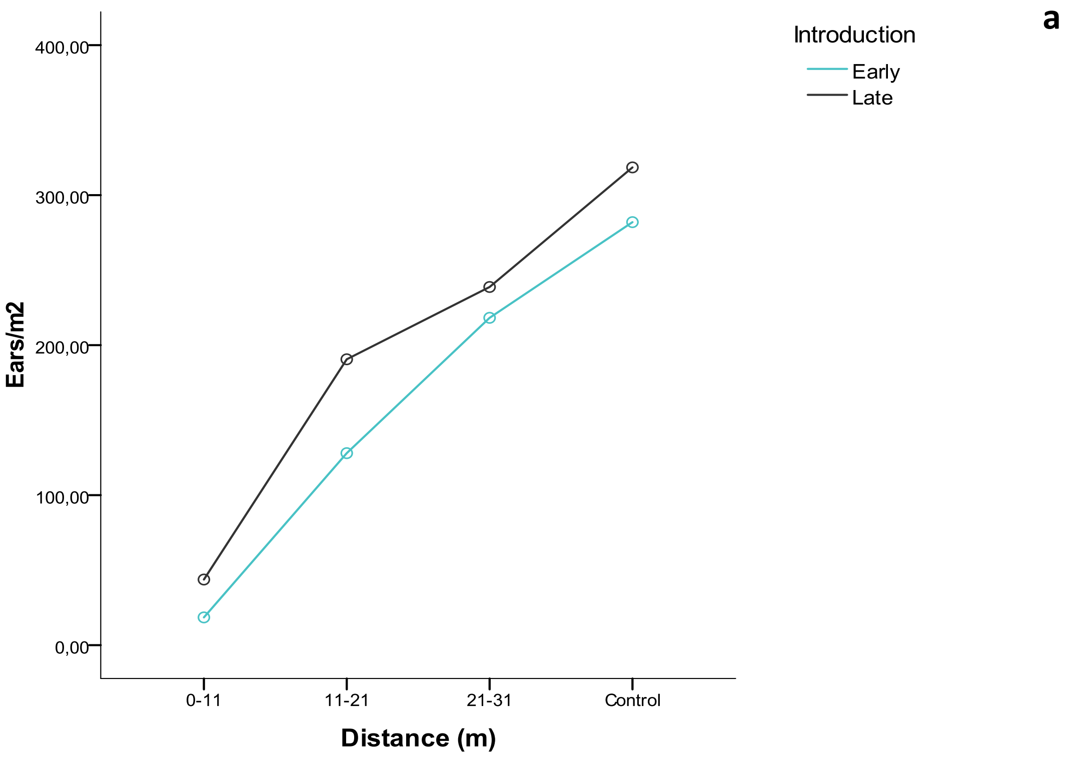
The yield components were affected only by the distance from the hen house (Table 5). The number of *ears* m^{-2}, the *total DW* and the *total FW* close to the hen house (1-11 m) were significantly lower than at 11-21, 21-31 m and the control. All the variables showed a significant increase with further distance from the hen house, while total DW at 11-21, 21-31 and the control was not significant different (Table 5 & Fig. 10a,b,c). High number of ears and values of total FW and DW appear to be linked with the high average yield observed when the distance from the hen house was increased (Table 5 & Fig. 10 a,b,c,d).

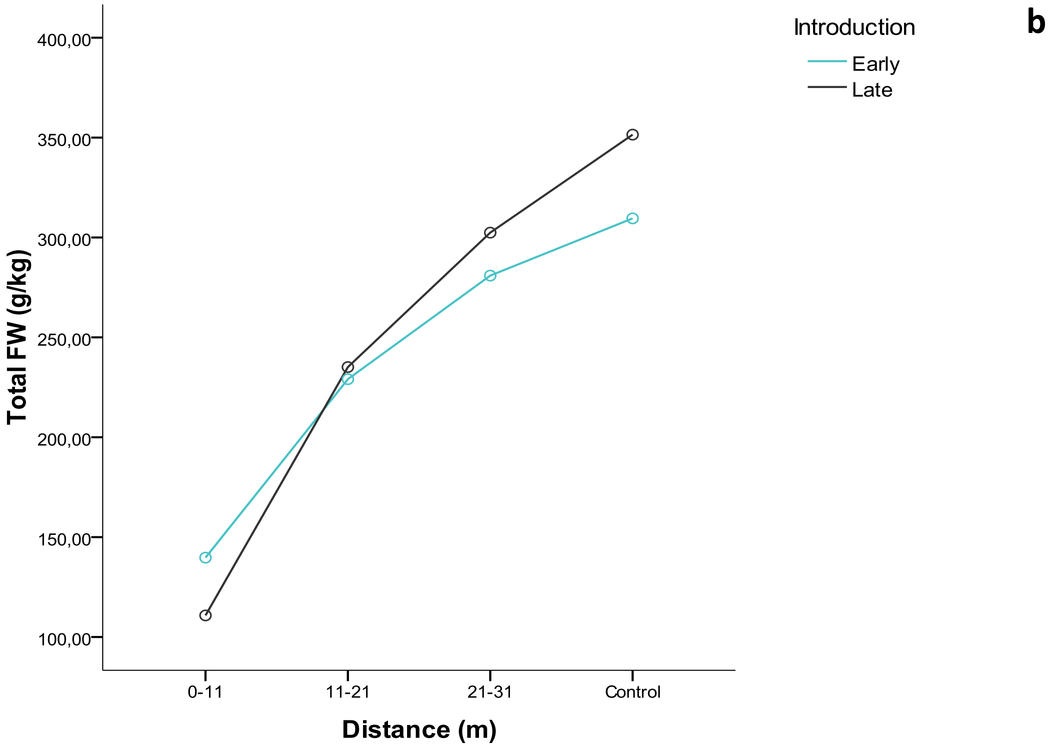
Table 5. Influence of the broiler introduction date (Early vs. Late) and distance from hen house (1-11, 11-21, 21-31 or control) on yield and yield components of the barley cultivation at final harvest of barley.

	Ears m^{-2}	Total FW (g kg^{-1})	Total DW (g kg^{-1})	Yield (Kg ha^{-1})
Introduction (I)				
Early	161.68	239.81	198.77	52.94
Late	197.90	249.95	209.45	67.25
Significance	ns	ns	ns	*
Distance (D)[2]				
1-11 m	31.12 a	125.26 a	114.05 a	6.15 a
11-21m	159.29 b	232.10 b	201.69 b	55.11 b
21-31m	228.50 bc	291.67 bc	241.98 b	82.35 bc
Control	300.25 c	330.51 c	258.74 b	96.76 c
Significance	***	***	***	***
I×D	ns	ns	ns	ns

[1] *, ** and *** refer to P values < 0.05, < 0.01 and < 0.001, respectively; ns = not significant.

[2] No mean separation for main effects is presented whether the interaction effect was significant ($P < 0.05$); Different letters indicate significant differences according to Scheffé test ($P < 0.05$).


a
Introduction
Early
Late
Ears/m2
400,00
300,00
200,00
100,00
0,00
0-11
11-21
21-31
Control
Distance (m)


b
Introduction
Early
Late
Total FW (g/kg)
400,00
350,00
300,00
250,00
200,00
150,00
100,00
0-11
11-21
21-31
Control
Distance (m)

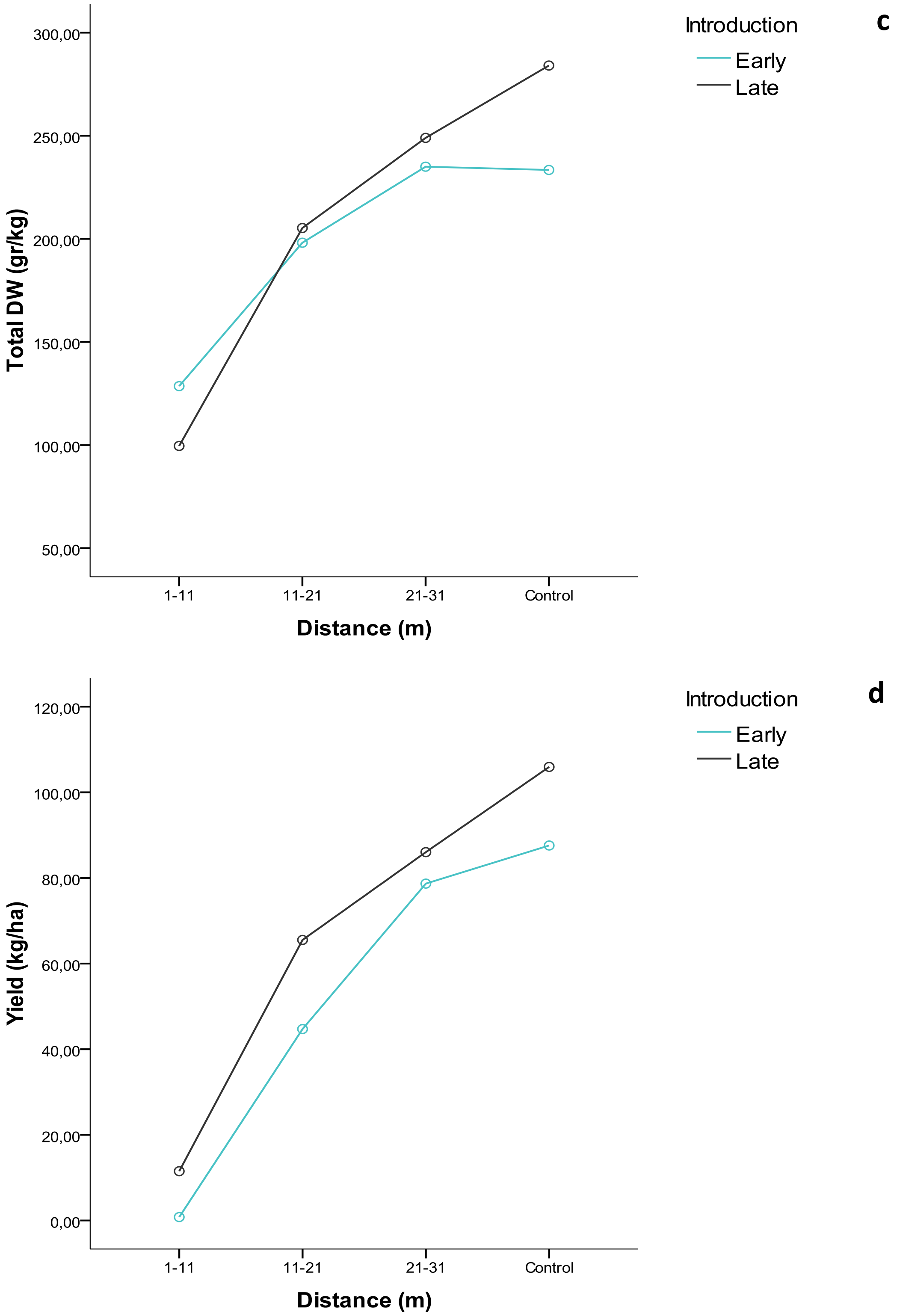


Fig. 10 a,b,c,d. Barley ears m^{-2}, total fresh weight (gr), total dry weight (gr) and yield (kg ha^{-1}) for early vs. late broiler introduction date at different distances from the hen house (1-11, 11-21, 21-31 m or control) at final harvest.

Yield was affected by both the introduction and the distance. Plots in which broilers were introduced late had a significantly ($p<0.05$) higher yield than when broilers were introduced early. Moreover, yield was the highest at the control plots reaching 96.76 kg ha^{-1}, while the plots close to the hen house (1-11 m) yielded only 6.15 kg ha^{-1} (Table 5 & Fig. 10d). The yield of the plots at 11-21 and 21-31 m from the hen house did not differ with each other but it was significantly higher than at 1-11 m and significantly lower than the control. Finally, yields of both the early and late introduction date treatments were significantly lower than the corresponding controls (Fig. 11). Yield in the early introduction experienced a significant decrease of 43%, while in late introduction 39% compared to the corresponding controls.

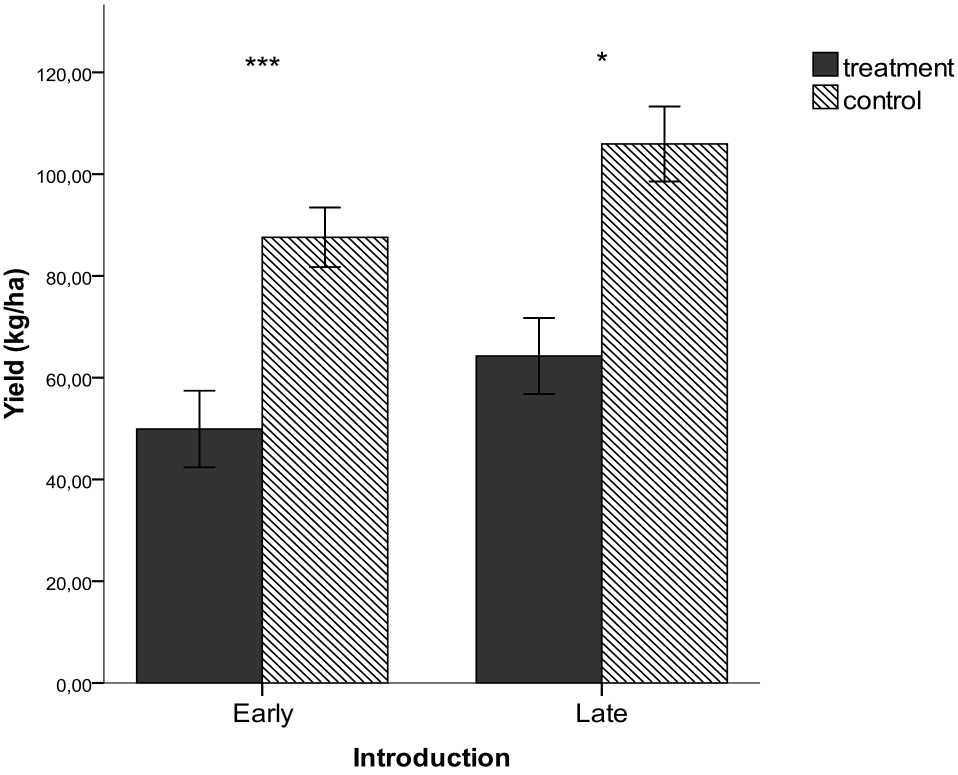


Fig. 11. Yield (kg ha^{-1}) for early, late broiler introduction date vs. early, late control at final harvest of barley. *P* values < 0.05, < 0.01 and < 0.001 are indicated as *, ** and ***, respectively; ns = not significant. The bars represent the standard error of the means.

The spatial pattern of the yield was further analysed by constructing maps (Fig. 12). The maps below were designed in a small scale according to the field layout. The maps show that the yield was lowest close to the hen house and increased with further distance from the house (the darker colour indicates higher yield among the plots). Moreover, it could be observed that in the late introduction, yield was more uniformly distributed among the plots, while in the early introduction some zones were formed (Fig.12).

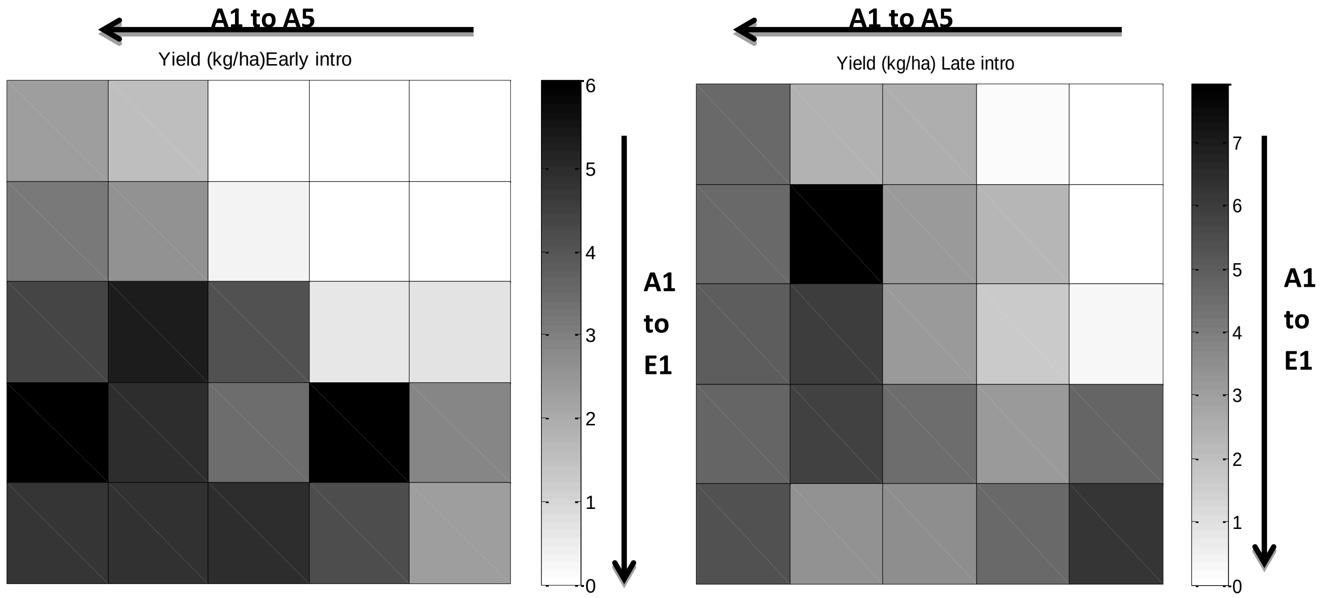


Fig. 12. Spatial distribution maps of average yield of barley per subplot in Early (left) and Late introduction date fields (right). Black and white represents high and low yields, respectively.

4. Discussion

This experiment aimed to elucidate the potential interactions, synergies and trade-offs of the incorporation of the broilers in barley cultivation, in the Netherlands. In this context, the role of the broiler's introduction date and the distance from the hen house was defined in order their effects on the crop growth, yield and soil fertility to be explored.

The sampling methodology and the subsequent integrated analysis approach allowed studying the manifold interactions among key variables and factors and deliver a better insight of their effects on plant growth, the final yield and the soil properties. To the best of our knowledge, until now there are no other studies focusing on crop-poultry system and exploring the advantages and disadvantages of such system, which could be used to compare with our findings. Related studies were recently performed in rice production systems with fishes and ducks (Xie et al. 2011, Khumairoh et al. 2012) and also in orchards and vineyards (Ako and Tamaru 2006; Clark and Gage 1996; Clark and Gage 1997). The latter experiments which included poultry were mostly focused on their ability to suppress the weeds and insects. Nevertheless, single key aspects and variables that were found in this study will be compared with the available literature.

Crop performance

Plant growth variables

The effect of the introduction date (Early, Late) and the distance from the hen house (1-11, 11-21, 21-31 or the control) differed among the plant growth variables (Height, stem DW, leaf DW, Leaf stem ratio, SLA and LAI). The incorporation of the broilers in the field and specifically their foraging behaviour led to significant changes in barley growth. The plots in which the broilers introduced late in the growing period had overall higher performance as indicated by all the growth variables, compared to those that the broilers introduced earlier. Late introduction date resulted in about 13 ± 2.11 cm taller plants and an average increase of 58.29 % of the stem DW, compared to the early introduction date. The study of Birnholz (2014), which indicated a relative low pecking rate for the late introduction date broilers as compared to the early introduction broilers, supports our findings. In line with that, it was stated that the total number of the broilers outside of hen house in the late introduction date was significantly lower than the number of the broilers in early introduction.

The early broiler introduction took place at the end of the jointing stage of the barley crop (38 Zadoks), whereas at the late introduction broilers were introduced at the end of the booting stage (49 Zadoks) (Appendix II.). According to Fohner (2002), at the stage of booting the plant has reached almost 50% of the dry matter weight that will eventually obtain at full maturity. However, during the jointing stage the leaves account for more than two thirds of the plant, and the number of potential grains and eventually the potential grain yield is determined (Collen, 2006). Since the maximum height of barley is around 90 cm and even less at later growth stages, it could be easily reached by the broilers considering their relative height. Indeed, visual observations confirmed that the broilers were damaging whole plants by pecking the leaves (removal of photosynthetic tissue) and later in the season the pickelets (head clipping). During the entire stay of the early introduction group at the field, the plants were vulnerable to broiler's pecking (vegetative growth and filling of the grains), but for the late introduction group the plants were vulnerable only in the first weeks (filling grains) of their stay. The leaf DW, SLA and LAI did not differ significantly between the two broiler introduction dates, but after the broiler's introduction they decreased dramatically due to the damage caused by them. Taking all these into consideration, it may be argued that the early broiler introduction group caused higher damage in the plants due to their foraging behaviour, and crop growth stages vulnerability.

Regardless the introduction date, the differences in plant growth variables that occurred among the distances from the hen house corroborates that the presence of the broilers in the barley field was detrimental. Barley height, stem DW, leaf DW and leaf stem ratio were significantly lower, at both introduction dates, close to the hen house (1-11 m) than the control. The effect of the broilers at 11-21 and 21-31 m was not so pronounced, but still when it comes to stem and leaf DW, resulted in lower values than the control. Moreover, leaf stem ratio experienced more dramatic decline during time at 1-11, 1-21, 21-31 m compared to the control. In accordance with our findings, Birnholz (2014) highlighted that the broilers were mostly concentrated close to the house (<5m) and that their number decreased dramatically with increasing the distance from the hen house. Furthermore, as the amount and the duration of the leaf area is positively correlated with the dry weight accumulation (Power et al. 1967), any damage of the photosynthetic tissue (leaves) could have unfavourable results in the crop performance and the potential yield.

Plant nutrient content

Nutrient concentrations of N, P and K in stems were lower than those in grains, reaching values of ≤1 % and ≥1 % respectively. Both in stems and grains, early introduction date resulted in higher nutrient concentrations, compared to the late introduction date. The presence of the broilers and subsequently the available raw manure in the field during the jointing growth stage (early introduction date), may have resulted in increased nutrient uptake by the plants. In contrast, the release of the broilers later in the growing season (booting growth stage) did not have any effect on the plant nutrient uptake. This finding is in line with Collen (2006), who reported that 35% of the final uptake takes place during the stem elongation-jointing growth stage, while the nutrient uptake decreases rapidly in the following stages (booting, ear formation).

Furthermore, the tendency of the broilers to stay close to the house (1-11 m) resulted in pronounced N, P and K concentrations compared to 11-21, 21-31 m and the control, in barley stems and grains, but only when the broilers were introduced early (5 weeks after sowing). Thus, the deposition of larger amount of the raw manure that the broilers were producing close to the hen house was used by the plants only during the early growth stages. In accordance with this, Malhi et al (2006) reported that the maximum nutrient uptake rate of barley occurred between tillering and stem elongation stages. In addition, in our study the fresh/raw manure that was deposited in the soil by the broilers was immediately available to the plants, after the broilers were released in the field. Many studies have shown that fresh poultry litter has high N mineralization (percent total organic N converted to inorganic nitrogen) (Tyson and Cabrera, 1993; Preusch et al., 2002). In addition, Murwira & Kirchmann (1993) proposed that the application of composted manure in maize fields should better be done before sowing due to nutrient immobilization, while fresh manure achieved better synchrony between N release and plant uptake six weeks after sowing.

Chemical soil properties

The total N in the soil was not affected by the incorporation of the broilers at 0-5 cm, but total N at 5-30 cm was increased at 11-21 and 21-31 m from the hen house at late introduction date, probably due to N leaching. Nevertheless, both introduction dates resulted in increased NH_4^+ at 0-5 cm, but only the early introduction date increased NH_4^+ at 5-30 cm. Fresh manure can increase soil N total (Irshad et al. 2013), but also has higher N mineralization rates compared to composted manure (Tyson and Cabrera, 1993; Preusch et al., 2002). Moreover, Amanullah (2010) reported that the higher mineralization rates (reaching 56 %) occurring in fresh manure could be attributed to the low C: N ratio. In our experiment, the reduced soil N total and the increased NH_4^+ may indicate that N was mineralized rapidly through time and was available for the plant uptake. In addition, the fact that N mineralization is increasing over time in the lower depths (Cassman and Munns, 1980) could explain that early introduction date resulted in increased NH_4^+ at lower soil depth (5-30 cm).

Regarding the NO_3^- concentration in the soil, the late introduction date at 1-11 m resulted in the highest concentration both at 0-5 and 5-30 cm. The higher N uptake from the plants due to better synchrony in the early introduction date resulted in lower NO_3^- concentration, while the late introduction date led to higher residual levels in both soil layers at the end of the season. The overall high concentration of NO_3^- at 5-30 cm is in line with the study of Samuel and Ebenezer (2014) that reported NO_3^- can reach lower soil depths because is very soluble in water and highly mobile in contrast with the NH_4^+ which is less vulnerable to losses from soils by leaching. Finally, the higher increase in NH_4^+ than in NO_3^- concentration that is recorded in the current study implies that the rate of ammonification was higher than the rate of nitrification. Thus, the soil conditions might have favoured ammonifying bacteria than the nitrifying bacteria (Samuel and Ebenezer, 2014).

The early introduction date of the broilers resulted in higher concentration of total and available P at 0-5 cm at the final harvest, most likely because of the longer stay of the early introduction date broilers outdoors during the day (Birnholz, 2014). At 5-30 cm the concentration of the available P was higher when the broilers were incorporated in the field in comparison with the control. The elevated available P values at harvest may be attributed to the slow release rate of P. Materechera and Morutse (2009) also indicated that P from poultry manure was mineralized slowly in a maize cultivation resulting in high residual levels in the soil at the end of the season. The high residual levels of P could have contradictive consequences. Nyakatawa et al. (2001) have shown that the residual soil P could increase the quality and the yield of the succeeding crop, while Sharpley et al. (1994) and Sistani et al. (2007) highlighted that excess of P in the soils can be released in nearby water bodies through leaching and run off.

Similarly to soil P, K concentrations were higher when the broilers were introduced early at both soil layers (0-5, 5-30 cm). At 0-5 cm the highest K concentration was observed at 1-11 m from the hen house. These results can be verified from the behaviour of the broilers to stay close to the house and also the longer stay of the early introduction date group out of the house during day (Birnholz, 2014).

The higher nutrient concentrations found close to the hen house in this study, are in line with the findings of related studies which indicate the formation of zones with different manure deposition regarding the distance from the house (Eriksen and Kristensen 2001; Pedersen et al. 2002; Riviera-Ferre et al. 2007; Antonissen & Lantinga NP). Moreover, pH levels were expected to increase in the plots where the broilers were introduced, however only slight increase from 6.5 to 6.9 was observed, most likely because of the buffer capacity of the manure (Boateng et al. 2006; Alitalo et al. 2012).

Finally, some aspects about the environmental risks coming with the unstable fresh manure should be taken into consideration. Nahm (2003) reported that fresh broiler manure without litter has high water content (60-70%) and is susceptible to evaporation and to volatilization. The losses due to volatilization from the surface of manure when it is exposed to the air substantial and could pose environmental treats. For instance, Wolf et al. (1988) stated that 37% of the total N in the soil after poultry manure application was volatilized in 11 days; hence the amount of available N for plant uptake was significantly reduced. In the end, as it was described before, the accumulation of P should be monitored periodically in order to minimize the effects on ground and surface water.

Yield and yield components

The final grain yield is the outcome of multiple morphological and physiological processes that take place during the crop growth and development. Yield is defined by the interactions among different yield components that were affected differently by incorporation of the broilers and the growing conditions.

The incorporation of the broilers into the barley cultivation was detrimental for the final grain yield. Yield was significant lower in the plots where the broilers were released, in comparison with the corresponding controls. However, the overall better crop performance of the plants in the plots in which the broilers were introduced late led to a significant increase of 27% in the final yield, compared to those where the broilers were introduced early. Fettell et al. (2010) reported that the available N at stem elongation-jointing growth stage increases the final yield by maintaining the existing tillers and ensuring rapid canopy expansion. In the current study, this is not the case because even if there was better synchrony of the nutrient release and uptake from the plants in the early introduction date, this was not enough to compensate for the damage of the broilers foraging behaviour.

The number of ears m^2, the total FW and DW were significantly lower at 1-11 m due to the tendency of the broilers to gather close to the house. This uneven distribution proved to link the higher number of ears m^2, the total FW and DW with the higher average yield observed when the distance from the hen house was increased. Many studies have reported that growth variables such as the dry matter production and LAI have been identified as major determinants of the potential yield (Shortall and Liebhardt, 1975; Thakur and Patel, 1998; Sun et al., 1999; Boateng et al. 2006). In addition, Tesfaye et al. (2006) highlighted the importance of high LAI attainment during the whole growth and especially at the flowering stage, which could minimize soil water evaporation intercepts and convert the available solar radiation into dry matter which in turn will redistributed into the seed. In the present study, the foraging behaviour of the broilers on the leaves and spikes (decreased LAI, SLA, stem and leaf DW) led to the reduction of the photosynthetic capacity, the overall growth of the plants and the number of fertile spikelets (decreased grain number). Hence, the combination of all these could attribute to the final yield loss.

Finally, it is noteworthy to mention that during the current study, unstable weather conditions and two fungal diseases on the plants (leaf rust: *Puccinia recondita* and covered smut*: Ustilago hordei*) were observed. In the beginning of the season the weather was relative cold and then wet weather with high temperatures took place. Late in the season, at critical growth stage for the plants, drought conditions were prevailed. The low temperatures rendered the sowing possible not earlier than May, while the late-season drought (before and during anthesis) contributed to further yield loss (Fig.1). In agreement with that, Collen (2006) stated that the water stress and the high temperatures at the critical period from 2 to 3 weeks before anthesis result in reduced spikelet production and survival, which in turn has great impact on the yield. The lack of available water and the occurrence of diseases impair photosynthesis and consequently may reduce grain filling. In order to minimize the water stress from the drought conditions, irrigation was applied three times. Unfortunately, one week after the irrigation, a heavy rainfall occurred and resulted in water logging mostly in the plots close to the hen house (the plants density in the plots close to the house was reduced due to the damage occurred by the broilers). Fettell et al. (2010) reported that barley is very susceptible to water logging specifically in the early growth stages, but it could be also detrimental to the survival of the plants at later growth stages. To conclude, the environmental conditions might play an important role in the plant growth and consequently could account for the yield loss.

5. Conclusion

The current study aimed to elucidate the interactions, benefits and trade-offs of the incorporation of broilers in barley cultivation. The incorporation of the broilers into the barley cultivation had a negative effect on the plant growth and yield. The significant yield loss demonstrates that the foraging behaviour of the broilers on the leaves and spikes reduced the photosynthetic capacity and the overall growth of the plants, and also the number of fertile spikelets. Nevertheless, late introduction of the broilers prevented some of yield loss because of the lower growth damage, which could be attributed to the late growth stage of the plants when the broilers were released and the reduced foraging rates of the broilers. The early introduction, on the other hand, showed better synchrony between the nutrient release and plant uptake, reaching increased nutrient concentrations in stems and grains. However, this was not enough to compensate for the damage of the broiler's foraging behaviour. Moreover, the higher nutrient uptake by plants led to lower nutrient concentrations in the soil in the early introduction versus the late introduction, which could enhance the environmental sustainability. Based on our findings and taking also into consideration that the weather conditions and the diseases are highly unpredictable, it may be concluded that late introduction date resulted in better growth performance and yield, but early introduction resulted in higher plant nutrient uptake and lower residual nutrients in the soil. These results should be further explored in the following studies. Adequate assessment of the integrated crop-livestock system will require the examination of various performance aspects as well as environmental and economic outcomes in varying weather conditions. It could be recommended that such effort should include different crops, a mobile hen house, fewer broilers, an economic analysis and monitoring of environmental impacts. Crops that are taller than barley may be less vulnerable to the broilers pecking at early growth stages. In addition, the reduction of the broiler density could be another option for managing yield loss. However, an economic analysis of the yield loss and the potential gain from the broilers sale should also be under consideration. The integration of different key factors and variables that will be studied in this long-term research might enhance our understanding of the intrinsic factors and processes governing a sustainable establishment of integrated crop-livestock systems.

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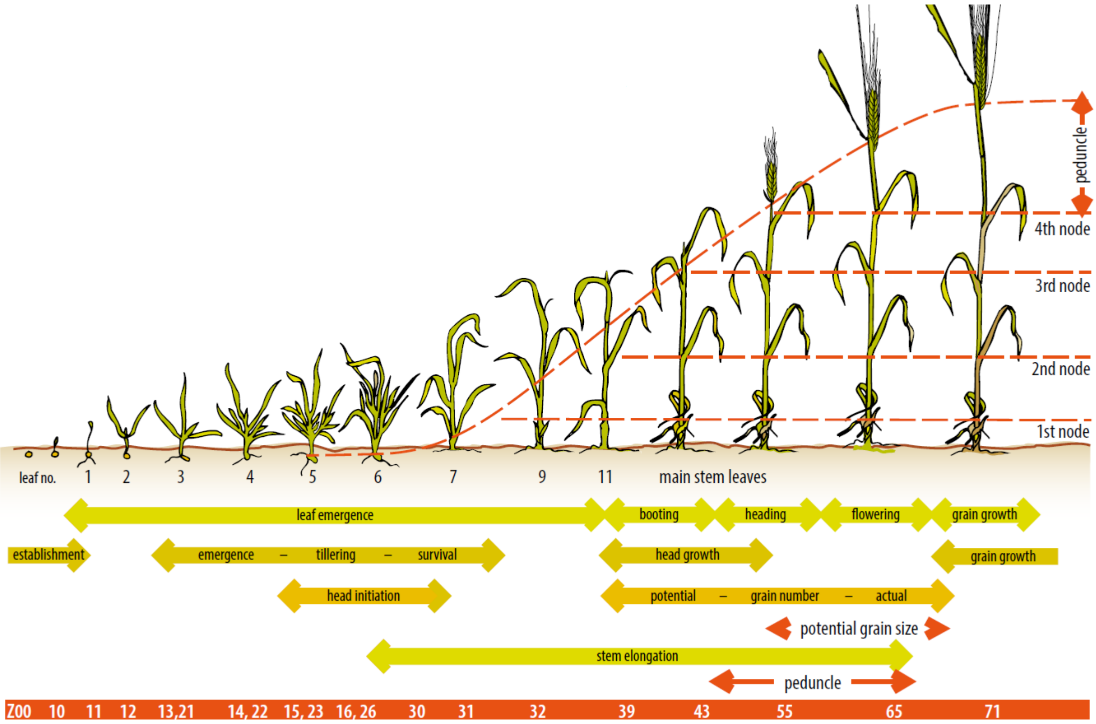
Appendices

I. Initial soil chemical properties

Table 6. NH_4^+ (mg kg^{-1}), NO_3^- (mg kg^{-1}), PO_4 (mg kg^{-1}) and pH at 0-30 and 30-60 cm prior the incorporation of the broilers in the fields.

	0-30 cm			30-60 cm			
	NH_4^+	NO_3^-	PO_4	NH_4^+	NO_3^-	PO_4	pH
Date	(mg kg^{-1})						
25/5	15.87	5.36	-	6.94	4.25	-	6.4
16/6	4.20	15	0.80	1.10	11.8	0.50	6.5

II. Life cycle of barley (Zadoks scale)



Fettell et al. (2010)