Effect of Seed-Beds on the Cultivation of Radicchio

(*Cichorium intybus* L., *Rubifolium* Group)

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Abstract

The use of raised beds (i.e., ridged soil layers) to cultivate vegetables can improve soil quality, crop performance, water use and even reduce soil erosion. Although those advantages are well known and documented in the literature for many vegetable species, Radicchio, a particular variety of chicory, is usually cultivated in flat seed-beds and, therefore, the achievable benefits of raised beds for this vegetable are not yet known. The possibility to grow plants of Radicchio on raised beds is here evaluated by comparing the most important yield performances indicators deriving from the adoption of this practice (grown plants percentage, average head weight, marketable yields, and net incomes) with the same indicators recorded with a conventional practice making use of flat seed-beds. The results evidenced that raised beds for Radicchio had a statistically significant effect on the average head weight (+55.45 g plant^{-1} with 15-cm beds) with significant increases of field yields (up to +30.6%) and net incomes (up to +29.7%) on the trials with flat seed-beds. The experiment showed that the production of chicory can take an economical advantage from the use of raised seed-beds and, therefore, this system is preferable to the traditional cultivation practice.

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1 Introduction

Radicchio (*Cichorium intybus* L., *Rubifolium* group) is a particular variety of chicory, also known as "Italian chicory". This crop group includes at least six cultivars, called in accordance with their prevalent colour ("*rosso*" or red, "*variegato*" or streaked, "*bianco*" or white) and city/town of origin ("*Chioggia*", "*Verona*", "*Castelfranco*"), e.g.: "*Rosso di Chioggia*", "*Rosso di Verona*", "*Rosso di Treviso tipo Tardivo*", "*Rosso di Treviso tipo Precoce*", "*Variegato di Castelfranco*", "*Bianco di Chioggia*". Most of them are characterised by deep dark red leaves and bright white ribs as well as by a discreet bitterness of the taste. In last years radicchio has assumed considerable importance in horticulture, being a valuable vegetable appreciated not only for his coloured and attractive appearance, suitable for fresh-cut mixed salads, but also for his particular organoleptic and sensorial characteristics. Its cultivation is diffuse not only in Veneto region (North-Eastern Italy), where the modern cultivation of this plant began in the fifteenth century, but even in many other states of the world [10, 17, 23].

Radicchio has a good adaptation to different soil conditions, but in the heavier soils (fine-textured soils) it may encounter problems due to water logging, also related to the frequent and abundant irrigation required by this crop, and to the consequent troubles to carry out the soil tillage and other operations [22]. Moreover, water logging is also one of the major causes of diseases (e.g., root rot) and other problems for the plants (e.g., anoxia), which leads to negative effects for the radicchio plants such as a stunted growth. Another consequence is the need for more pesticide distributions, in order to maintain high both the yield and the crop quality [8].

Among the different solutions proposed hitherto to reduce water logging and improve plant growth, besides the appropriate soil management practices aimed at preventing surface crust and subsoil compaction, there is the possibility to grow the crops in raised beds [25, 28]. Raised beds are designed to create and maintain [14]: (1) a significant proportion of large pores within the ground, to have good aeration, infiltration and drainage; (2) a deepened seedbed that does not limit the growth of roots; (3) a substantial hydraulic gradient to stimulate lateral drainage and avoid waterlogging. In fact, a number of studies demonstrated that raised beds can improve soil quality, crop performance, water use and reduce erosion in vegetable production systems, especially when permanently used [7, 9, 13, 15, 27]. In chufa and other crops, especially root and tuber crops, flat raised beds can increase the yield without affecting negatively the final quality of the product [21]. In addition, raised bed cultivation requires machinery to pass up and down along the furrows, useful to create a controlled traffic during all farming operations [12]. This means the soil within the beds is never compacted by machinery. On the other hand, tractors and other machinery need to be properly

equipped to fit the bed width and shape (mostly for transplanting and hoeing operations). Finally, the results presented by Hussain et al. [16] revealed that the energy input on raised bed production systems was 7% lower than on conventional basin production systems.

Although many crops are grown on a raised bed to benefit from the positive and demonstrated effects in their production, radicchio is usually cultivated in flat seed-beds, also in fine-textured soils, mainly for traditional habits.

Therefore, the aim of this research was to evaluate the yield performance of radicchio cultivated in raised beds by comparing this practice with the conventional farmers' practice making use of flat seed-beds. An economic analysis was also performed to complete the comparison.

2 Materials and Methods

2.1 Test trials

The test trials concern the comparison between the traditional method of preparation of the transplant bed, directly on the ground (i.e., the conventional flat seed-bed), and the use of a raised floor (i.e., the raised seed-bed), having a height of some centimetres above the ground level.

The trials were performed during the 2009-2012 production period on a commercial farm located in Mirano (in the province of Venice, Italy; 45°30'44.748"N, 12°5'57.790"E), specialized in the production of many vegetables, including radicchio "*Rosso di Treviso*".

Meteorological data concerning the whole period of observation (four years) were recorded by the nearest regional weather station and are reported in Figure 1.

The soil type was Oxyaquic Eutrudepts fine-silty, mixed, mesic (USDA Soil Taxonomy classification) and Gleyic Calcisols (Orthosiltic) (World Reference Base for Soil Resources classification) [1]. The soil texture was silty-loam (Table 1) with an organic matter content of 1.8 %, pH 8, cation exchange capacity (CEC) of 16 meq/100 g; the total available water capacity (AWC) was 220 mm m^{-1} and the saturated hydraulic conductivity was 11.5 mm h^{-1}. The AWC of the top soil layer (having a thickness of 0.30 m), where plant roots were distributed, was 66 mm. Due to the high level of silt, this type of soil is usually more subjected to degradation and compaction than sandy soils, and, for this reason, it is considered to be less suitable for horticulture.
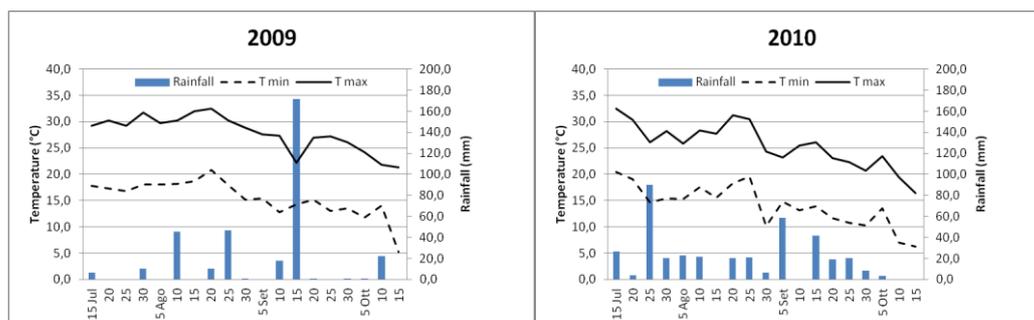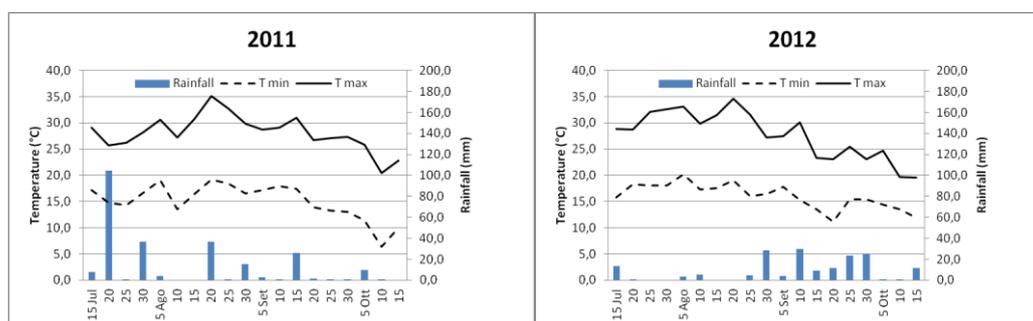
Figure 1 – Five-day averages of maximum and minimum temperature (continuous and dotted black lines) and cumulative rainfall (blue vertical bars) recorded during the four years of experiment.

Table 1 – Characteristics of the soil of the test site (values referred to 0÷45 cm depth).

Parameter	Unit	Value
Content of clay, sand, silt, organic matter	%	19.0; 24.0; 57.0; 1.8
Available water capacity	mm m^{-1}	220
Saturated hydraulic conductivity	mm h^{-1}	11.5

Two contiguous plots were set up, each one with an extension of about 2000 m^2: one was prepared with the conventional planting system (no raised bed), the other one was instead prepared by using a bed-former machine (plot with raised bed).

The plots were tilled between the end of July and the first week of August of every year included in the experimentation period. Seedlings of radicchio "*Rosso di Treviso tipo Precoce*" (early cultivars "*Franchetto 6*" and "*Cobra 11*") were transplanted into the field plots during the second week of August with a plant spacing of 0.26 m in the row and 0.60 m between rows (thus having a crop density of 6.41 plants m^{-2}). During the experiment, the following crop rotation was adopted: radicchio was followed by green manure (leguminous and crucifer mixture) and cabbage. For both plots and in every year of the experiment, ammonium nitrate (title 26% N) was applied during pre-planting tillage at a rate of 100 kg ha^{-1} of N. No phosphorus or potassium doses were applied, as the content of these mineral elements in the soil was high enough.

An irrigation system with low-volume mini sprinklers (model "Super10") on a stand (NaanDanJain, Israel) placed in a triangular layout about 10-m apart was installed. The sprinklers have a nominal flow rate of 530 L h^{-1} at 3.5 bar. The installation and operation of systems of these types allow for a more uniform irrigation and a reduction in runoff, both very important to ensure a good irrigation efficiency [26], an application of smaller size droplets, shorter and more frequent irrigation cycles, which have proven to be beneficial for horticultural crops such as radicchio, carrots, onions, potatoes and lettuce [6, 11]. Irrigations were scheduled every two days (but not in the rainy days) applying a water volume of about 12 mm.

At the end of each season (i.e., at the second half of October), plant samples were taken to estimate the crop yield. Before harvesting, seven plots for each treatment were individuated along the central part of each field; each parcel had an area of

3.75 m² and included ideally 24 plants (6 rows with 4 plants each). After the harvesting, the chicory heads of each parcel were cleaned and prepared according to the standard practices used for the heads assigned to be sold: the outer leaves were removed and a portion of the taproot was cut; then they were counted and weighted singularly to calculate the percentage of grown plants and the average weight of individual head.

2.2 The used bed-former machine

Different types of bed-formers can be used to create raised beds: the most diffused are pan-bed shapers and spool-roller shapers. The second type of machines is generally preferred because it is easier to operate and does not drag soil to the ends of the field, thanks to the presence of the shaping rollers [20]. Bed-former machines can also be combined with specific equipment for performing the secondary tillage and the seedbed preparation.

The machine used in this research is the "TSA 190" (Ortiflor, Italy), a semi-mounted (i.e., supported by two wheels during its operation on the field) stone-burier spool-roller bed-former implement machine. Its technical characteristics are reported in Table 2. This equipment was pulled by a farm tractor with the characteristics reported in the same Table.

Table 2 – Technical characteristics of the used equipment.

Machine	Quantity	Unit	Value
Bed-former implement	Overall height, length	mm; mm	2050; 2100
	Work width	mm	1900
	Mass	kg	760
	Required PTO speed	rpm	540
4WD farm tractor	Engine speed kept during the seed-bed forming operation	rpm	2100
	Nominal power	kW; HP	45; 60

The main working tools of this implement are two horizontal rotors: a front rotor with the blades working vertically the soil, a rear rotor equipped with small teeth and turning at a very high speed in the opposite direction with respect to the first rotor. This latter rotor shatters the most superficial clods, moves the biggest clods to the front rotor, levels the soil with the aid of a rear roller and lightly presses the soil on its surface. Two concave disks, adjustable in their distance, working depth and inclination, are used to form the lateral inclined sides of the seed-bed. Due to the complementary action of the two described rollers, the so-formed seed-bed has a stratigraphy characterized by several different layers of ground: fine ground at the surface and, below it, a ground with clods having a size increasing with the depth. This preparation is optimal for the sowing or for the transplanting and realizes also a good water drainage.

In the experiments described here, the raised-beds had a width of 160 cm allowing a seedlings transplanting in three rows. The seed-bed height studied during this experiment was 0 (non-raised seed-bed) and 15 cm (raised seed-bed); it was measured in correspondence of five different cross-sections of each parcel as the average height in three points positioned in correspondence of the seeding rows.

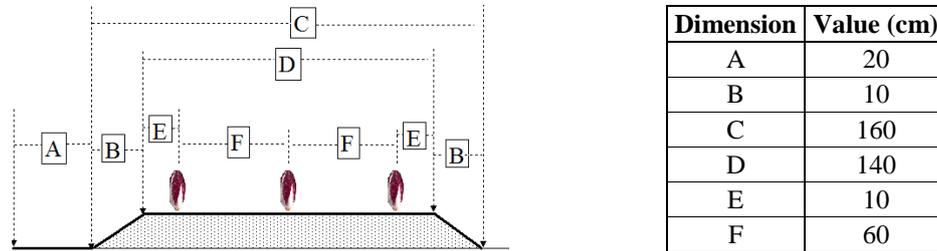The profile of the seed-bed used is schematized in Figure 2.

Dimension	Value (cm)
A	20
B	10
C	160
D	140
E	10
F	60

Figure 2 – Schematic of the seed-bed prepared with the "TSA 190" machine (the seed-bed height is not indicated, as it was object of the study presented here).

2.3 Statistical evaluations

All the collected data, concerning the percentage of harvested heads of chicory in each parcel and the average head weights (g plant^{-1}), have been elaborated statistically.

After an ANOVA test, aimed at evidencing the parameters of influence (significant factors) on each of the two above-indicated quantities (responses), a subsequent application of the response surface methodology (RSM) has allowed to calculate the coefficients of the regression function that describes the effects of the statistically-significant independent variables on each response.

The RSM is a very effective numeric tool that allows calculating, from a set of input data, an explicit polynomial regression-function that is the best approximation, in a limited validity domain, of the real function governing the phenomenon under study [3, 4 5, 18, 19]. Differently from other mathematical tools, such as artificial neural networks [2], RSM gives as a result an explicit polynomial function that is the first part of the Taylor series of a (unknown) real function $f(x_i)$ and can be used to study and/or optimize a system by making some quantitative predictions about the involved quantities. At the same way, the same function can be also represented graphically in some charts to enhance the immediacy of understanding and avoiding the reader any calculation.

Design-Expert 7.0.0 software (Stat-Ease, Minneapolis, MN, USA) was used for these calculations. The generic regression model used in this analysis (Response Surface Modelling) is a (multi-) linear model (*y*: generic predicted response, i.e. dependent variable; x_i: generic numerical factor, i.e. independent variable, with $1 \leq i \leq k$, $k \geq 1$; a_0 is the intercept; a_i are the coefficients of the linear terms, respectively):

$$y(x_i; 1 \leq i \leq k; k \geq 1) = f(x_i) = a_0 + \sum_{i=1}^{k} a_i x_i \tag{1}$$

According to the software suggestions, higher-degree models (up to the third degree) could not be used in the present case, due to the possible occurrence of the aliasing phenomenon.

In particular, the effect of the following three factors (one numerical, two categorical) on the two above-mentioned responses has been inquired (Figure **3**):

- the seed-bed height (numerical factor controllable by the farmer; two possible values: 0 cm, 15 cm)
- the transplanting year (categorical factor, summarizing all the environmental variability of climate; it can assume four possible values: 2009, 2010, 2011, 2012)
- the Radicchio cultivar (categorical factor with two possible values: "*Franchetto 6*", "*Cobra 11*")
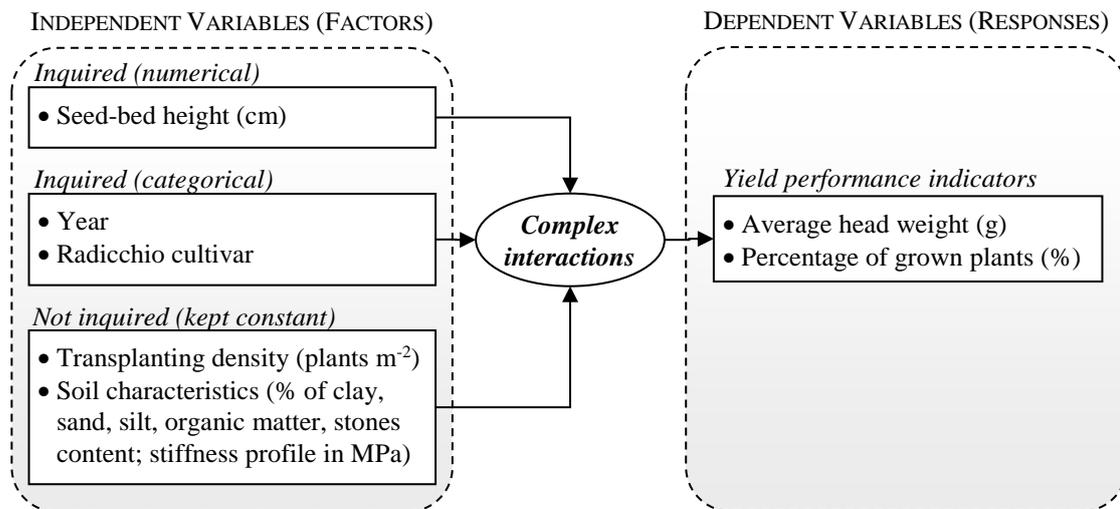

Figure 3 – Variables considered in the assessment of the seed-bed influence in the production of radicchio.

The choice of the variables to be inquired has been done carefully; the aim was to separate the eventual effects of this cultivation practice (→ *Seed-bed height*) from the climatic (→ *Year*) and varietal contributions (→ *Radicchio cultivar*), without rising too much the number of factor combinations in a factorial experimental design (i.e., the number of the parcels to be prepared). Therefore, all other possible independent variables (controllable by the farmer or not) were kept constant and, hence, not inquired in this study: the transplanting density (controllable variable) was set to the value used for this cultivation (6.41 plants m^{-2}), the soil characteristics expressed in term of composition (not-controllable variable) and stiffness profile (partially-controllable variable through tillage operations) were kept constant (i.e., excluded from the study) by using the same field for the experimentation. In fact, some preliminary samplings of the soil of the field used in this study showed a constancy of its characteristics.

The ANOVA, which is part of this methodology, lets the analyst identify the most significant factors and polynomial terms, thus operating a partial simplification of the resulting polynomial models on the basis of the p-values (threshold value: 0.05).

3 Results and discussion

The following Table 3 reports the data concerning the percentage of grown plants and the average head weight as a function of the adopted cultivation practice, i.e.

distinguishing them according to the presence or not of a raised seed-bed. In the following paragraphs a statistical evaluation of the obtained data has been given. The same table reports also the marketable yields calculated on the basis of the results of the experiment (i.e., on the basis of the parcels' data).

Table 3 – Synthetic data concerning the percentage of grown plants, the head weight and the marketable yield as a function of the cultivation practice.

Year	Seed-bed	Grown plants (%)		Head weight (g)		Marketable yield (t ha^{-1})	
		Mean	St. dev.	Mean	St. dev.	Mean	St. dev.
2009	Raised	58.3	17.3	300	75	11.2	4.1
	Flat	65.5	12.2	301	62	12.6	3.4
	Both	61.9	14.9	301	66	11.9	3.7
2010	Raised	83.3	10.3	353	68	18.8	4.2
	Flat	80.4	16.2	286	86	14.4	4.3
	Both	81.8	13.4	319	83	16.6	4.7
2011	Raised	81.0	11.7	380	41	19.7	3.8
	Flat	76.2	14.2	351	67	17.3	5.6
	Both	78.6	12.7	365	56	18.5	4.8
2012	Raised	83.3	9.0	537	39	28.7	4.0
	Flat	85.7	7.9	420	85	23.2	5.8
	Both	84.5	8.2	479	88	26.0	5.6

3.1 Percentage of grown plants

Notwithstanding some numerical differences, a preliminary ANOVA on the results concerning the percentage of grown plants (Table 4) shows that the variability recorded during the experiments is substantially related only to the year (the p-value associated to this factor is the lowest). Therefore, the observed variability is mostly due to external (i.e., environmental) factors, principally the weather conditions occurring year after year, having a known influence on the strength of the attacks by pathogens and soil insects (e.g., elateridae) occurring during the growth. As the plants were transplanted on the field, the number of red chicory heads counted at the harvesting is the result of the taking root and survival of the plants during all the growing season subsequent to the transplant.

Instead, looking at the p-values of Table 4, both the plant cultivar and the seed-bed preparation has no significant influence on this response and therefore causes not significant differences on the results. Concerning the plant cultivar in particular, this results was expectable, since both the considered cultivars were specifically developed to better adapt to the climatic conditions of the Po valley and, therefore, they have similar adaptation capabilities and resistance to the pathogens.

Table 4 – ANOVA on the data concerning the percentage of grown plants.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	Comments
Model	5195.75	5	1039.15	6.53	< 0.0001	significant
A-Seed-bed height	*1.31*	*1*	*1.31*	*8.221E-003*	*0.9280*	
B-Year	*5193.37*	*3*	*1731.12*	*10.88*	*< 0.0001*	
C-Radicchio cultivar	*558.04*	*1*	*558.04*	*3.51*	*0.0657*	
Residual	10182.22	64	159.10			
Lack of Fit	*539.37*	*4*	*134.84*	*0.84*	*0.5059*	*not significant*
Pure Error	*9642.86*	*60*	*160.71*			
Cor Total	15377.98	69				

Starting from a multi-linear model and removing the not-significant terms through a backward selection beginning from the least significant term, it is possible to calculate new values for the p-values and decide if going on with the factors' selection process until arriving to have a set of significant factors only, appearing in the final regression model.

If eliminating the least significant term (the seed-bed height in this case), the following p-values are obtained (Table 5). Note that the "*Radicchio cultivar*" categorical factor is still not significant and an eventual regression model accounting for two cathegorical factors will contain only the intercept, distinguished by the values of the categorical variables themselves (so it will be articulated in 2×4=8 different sub-models).

Table 5 – ANOVA for the first reduced response surface linear model (% grown plants).

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	Comments
Model	5194.44	4	1298.61	8.29	< 0.0001	significant
B-Year	*5192.21*	*3*	*1730.74*	*11.05*	*< 0.0001*	
C-Radicchio cultivar	*558.04*	*1*	*558.04*	*3.56*	*0.0636*	
Residual	10183.53	65	156.67			
Lack of Fit	*540.67*	*5*	*108.13*	*0.67*	*0.6456*	*not significant*
Pure Error	*9642.86*	*60*	*160.71*			
Cor Total	15377.98	69				

Eliminating also the factor "cultivar" and therefore leaving the year as the only influent factor (Table 6), we have only four sub-models having a constant value different in every year, numerically equal to the average percentage of grown plants recorded with both raised and flat seed-beds (Table 7, Figure 4).

Table 6 – ANOVA for the second response surface linear model (% grown plants).

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	Comments
Model	4636.41	3	1545.47	9.50	< 0.0001	significant
B-Year	*4636.41*	*3*	*1545.47*	*9.50*	*< 0.0001*	
Residual	10741.57	66	162.75			
Lack of Fit	*1098.71*	*6*	*183.12*	*1.14*	*0.3509*	*not significant*
Pure Error	*9642.86*	*60*	*160.71*			
Cor Total	15377.98	69				

Table 7 – Response surface models for the percentage of grown plants.

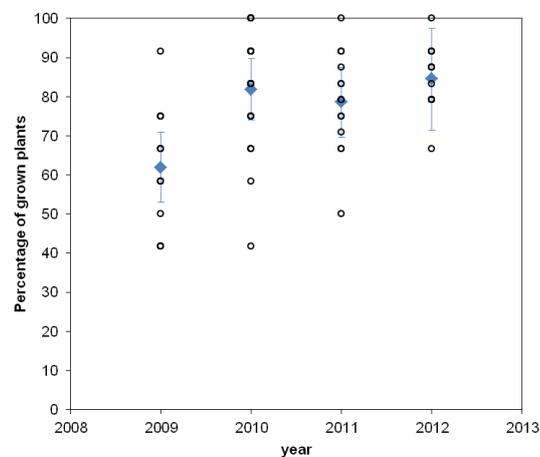| Year	Equation
2009	%plants = +61.90476
2010	%plants = +81.84524
2011	%plants = +78.57143
2012	%plants = +84.52381

Figure 4 – Percentage of grown plants with respect to the year (error bars are set to 95%).

The mathematical models reported here, very simple, allow to make comparisons between the outcomes of the various years. In fact, since globally there is no influence of the seed-bed height, as demonstrated by the ANOVA of Table 4, it is more immediate to compare the values of the overall averages (calculated from the data of flat and raised seed-bed together) of grown plants in each year, i.e. the intercepts of the linear models of Table 7.

In particular, it is possible to observe that the absolute lower value of the grown plants percentage regards the year 2009. Other than the attack of the soil pathogens, this was due to the exceptional and concentrated events of that year (see Figure 1). In fact, those events caused high-cumulated rainfalls, water logging and a plant stress leading to anoxia and death of some plants.

3.2 Average head weight

The ANOVA on the experimental data concerning the average head weight shows that the observed variability of this important parameter is caused by the height of the seed-bed (i.e., by the adopted method of cultivation) and by the year (mostly by the weather conditions recorded during the growing season of the plants), and not by the Radicchio cultivar (Table 8).

Table 8 – ANOVA on the data concerning the average head weight.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	Comments
Model	3.448E+005	5	68965.17	13.27	< 0.0001	significant
A-Seed-bed height	*52182.97*	*1*	*52182.97*	*10.04*	*0.0024*	
B-Year	*2.774E+005*	*3*	*92455.05*	*17.79*	*< 0.0001*	
C-Radicchio cultivar	*199.73*	*1*	*199.73*	*0.038*	*0.8452*	
Residual	3.327E+005	64	5198.28			
Lack of Fit	*33627.32*	*4*	*8406.83*	*1.69*	*0.1649*	*not significant*
Pure Error	*2.991E+005*	*60*	*4984.37*			
Cor Total	6.775E+005	69				

The influence of seed-beds on this response is a very interesting result because, by an agronomical point of view, it justifies the use of this cultivation technique. In fact, this result shows that the seed-bed preparation has a significant influence on the grown of the radicchio plants, thus modifying the average weight of each head: this practice manages to establish better physical conditions in the soil, particularly favourable to the development of roots and this has important (beneficial, in this case) consequences on the aerial part of the plants too.

The influence of the year (i.e., of the environmental conditions) also for this response is a predictable outcome for crops (like this one) planted in an open field, therefore exposed to any weather condition during their vegetative growth. It would be possible to eliminate this factor only by controlling the environmental variables and thus creating an artificial environment around the crops, i.e. a greenhouse. In this case, a partial control of environmental variables has been done by means of the irrigation.

The lack of influence of the cultivar is expectable also in this case, as both the considered cultivars of "*Radicchio di Treviso tipo Precoce*" were selected for the climate of the Po valley.

With the aim of finding a numerical correlation between the factors and the response, a backward selection criterion was applied also in this case. Starting from a multi-linear model (higher order models are not possible because of the phenomenon of aliasing, as indicated by the software) and removing the not-significant terms (in this case only the radicchio cultivar term was removed; Table 9), it is possible to obtain a reduced model composed by a set of linear equations, one per year (Table 10, Figure **5**). The seed-bed height is explicitly present in the equations with its own term, the year (hence, the weather conditions) has an influence on the intercept term value. In particular, the intercept is calculated so as the model forecast for 7.5 cm (i.e., the middle value of the seed-bed height range) is exactly equal to the experimental average head weight of each year, calculated considering all experimental data (flat + raised seed-bed).

Table 9 – ANOVA for the response surface reduced linear model (average head weight).

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	Comments
Model	346257.18	4	86564.294	16.99	< 0.0001	significant
A-Seed-bed height	*53814.01*	*1*	*53814.01*	*10.56*	*0.0018*	
B-Year	*292443.17*	*3*	*97481.06*	*19.13*	*< 0.0001*	
Residual	331258.37	65	5096.28			
Lack of Fit	*32196.01*	*5*	*6439.20*	*1.29*	*0.2794*	*not significant*
Pure Error	*299062.37*	*60*	*4984.37*			
Cor Total	677515.55	69				

Table 10 – Response surface sub-models for the average head weight (h in cm).

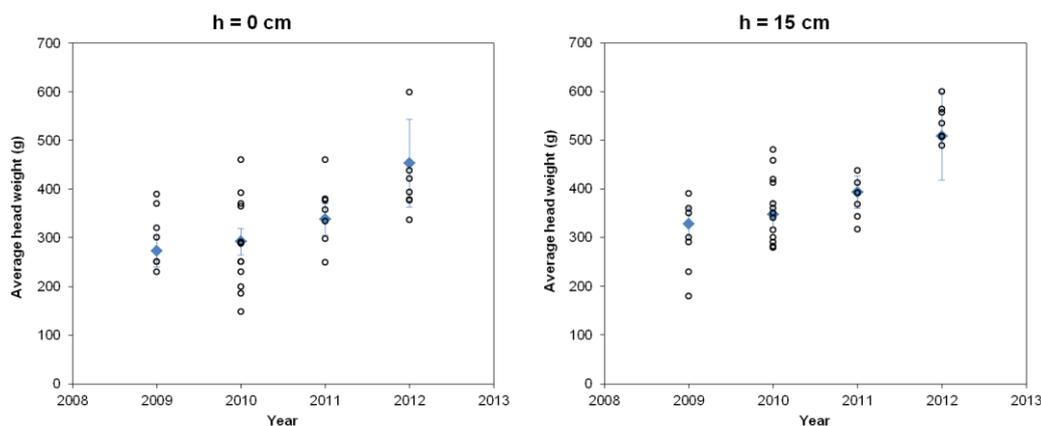| Year	Equation	Model forecast (g)		
		h=0 cm	h=7.5 cm	h=15 cm
2009	Av.wgt (g) = 272.98756 + 3.69690 · h	273	301	328
2010	Av.wgt (g) = 291.74531 + 3.69690 · h	292	319	347
2011	Av.wgt (g) = 337.73767 + 3.69690 · h	338	365	393
2012	Av.wgt (g) = 451.06248 + 3.69690 · h	451	479	507

Figure 5 – Visualization of the models' forecasts regarding the average head weight with respect to the year in the two indicated cases (seed-bed height equals to 0 and 15 cm, respectively); the error bars are set at 95%.

The reported equations show that the seed-bed is responsible for an increase in weight that is linearly variable with the seed-bed height (direct proportionality), estimated at about 3.70 grams per centimetre of elevation of the seed-bed: the average weight is about 55 grams higher for plants grown on a 15-cm seed-bed. The difference between a numerical prediction of the model and the corresponding experimental data (overestimation/underestimation by the model at 0/15 cm of seed-bed elevation) is the effect of the adverse/favourable weather conditions.

3.3 Economical convenience of the seed-bed forming operation on Radicchio

It is possible to account for the economical convenience of seed-bed preparation by considering the additional costs arising therefrom with respect to the higher revenues due to the increased production.

In particular, the comparison will be done with respect to a unit area, hence between the areal costs of the seed-bed operation ($c_{A,ridging}$) and the increase of areal revenue due to the same operation ($r_{A,ridging}$):

$$c_{A,ridging} < r_{A,ridging} \Rightarrow seed\text{-}bed\ operation\ is\ convenient$$
$$c_{A,ridging} \geq r_{A,ridging} \Rightarrow seed\text{-}bed\ operation\ is\ not\ convenient \tag{2}$$

The equation to be used to calculate the areal cost of the operation is the following:

$$c_{A,ridging}\left[\frac{\text{€}}{m^2}\right] = \frac{c_{tot,ridging}}{A_{tot,fields}} \tag{3}$$

The increase of areal revenue due to the seed-bed operation is instead calculated from the transplanting density $\rho_{transplant}$ (calculated from d_1, d_2 i.e., the inter- and intra-row distances in m), the percentage of grown plants $\%_{grown\ plants}$ and the average plant mass increase due to the ridging operation $\Delta \overline{m}_{ridging}$ (the mass difference due to the presence of a raised seed-bed with respect to the same yield without any ridged seed-bed), both estimated by using the numerical models presented in the previous paragraphs:

$$r_{A,ridging}\left[\frac{\text{€}}{m^2}\right] = \rho_{transplant} \cdot \%_{grown\ plants} \cdot \Delta \overline{m}_{ridging} \cdot r_{m,ridging} \tag{4}$$

with:

$$\begin{cases} \rho_{transplant}\left[\dfrac{plants}{m^2}\right] = \dfrac{1}{d_1 \cdot d_2} \\[4mm] \Delta \overline{m}_{ridging}\left[\dfrac{kg}{plant}\right] = \overline{m}_{ridge(15cm)} - \overline{m}_{plain} \end{cases} \tag{5}$$

By using the exposed equations with the data collected from the experimentation, we obtained the results collected in Table 11, net of the costs for irrigation and harvesting. The cost of the diesel oil has been considered equal to 1.0 € L^{-1} (in Italy it is subsidized by the state), the cost of labour 12.0 € h^{-1}, and the gross proceeds for the farmer in selling the radicchio 1.0 € kg^{-1}. For the ridging equipment, we consider an initial investment of € 25 000 with an economical duration of 10 years.

As visible, the economical convenience of performing this operation is evident, reaching net increases up to about 30% of the gross revenue recorded without the creation of any ridged seed-bed.

Table 11 – Main economical parameters resulting from the creation of 15-cm ridge; the yields were estimated by using the experimental data.

Year	Marketable yields		Increase of yields		Gross cost of ridging	Gross revenue		Gross increase of revenues	Net increase of revenues	
	(0 cm)	(15 cm)				(0 cm)	(15 cm)			
	t ha^{-1}	t ha^{-1}	t ha^{-1}	-	€ m^{-2}	€ m^{-2}	€ m^{-2}	€ m^{-2}	€ m^{-2}	-
2009	12.6	11.2	-1.4	-11.1%	0.0048	0.5040	0.4480	-0.0560	-0.0608	-12.1%
2010	14.4	18.8	+4.4	+30.6%		0.5760	0.7520	+0.1760	+0.1712	+29.7%
2011	17.3	19.7	+2.4	+13.9%		0.6920	0.7880	+0.0960	+0.0912	+13.2%
2012	23.2	28.7	+5.5	+23.7%		0.9280	1.1480	+0.2200	+0.2152	+23.2%

4 Conclusions

The use of a raised seed-bed for the production of radicchio had a statistically-significant effect in term of average head weight but not on the percentage of grown plants.

In fact, by an agronomical point of view, the creation of a raised layer of cultivation evidently allowed the plants to find a greater volume of permeable soil to be explored by the roots and, therefore, to have a greater development of the plant. This demonstrates the usefulness of this practice in reducing water logging and improving the plant growth, as resulting from the performed statistical analyses and as found also in other works of the literature concerning other vegetables. However, it was not effective in preventing or limiting attack by pathogens during the taking root and growing of plants, thus the percentage of grown plants was not influenced by the presence of a raised seed-bed but, rather, it was related only to the year, i.e. to environmental conditions experimented by the plants during the growing seasons.

The presence of a raised seed-bed and the combination with some difficult environmental conditions can result in different (opposite) contributions to the achievement of higher productions.

In particular, despite the presence of a raised seed-bed in some plots, the adverse environmental conditions of 2009 had important (negative) consequences both on the percentage of grown plants and on the average head weight. About this latter result, the experimental values concerning the two considered cultivation practices (with/without raised seed-beds) are very close one another. In fact, it should be considered that at the half of September there was a huge storm having a high cumulated rainfall (reaching 170 mm). The exceptionality of this event made pointless the effect of the seed-bed, even if for few days, but this event created however a stress on the plants with a consequent decrease in the average head weight and marketable yields. Notwithstanding the variegate situations of each year (and the situation of 2009 in particular, absolutely unclear by only observing the experimental data), by considering all the years at the same time, RSM technique has managed to find a model explaining the positive influence of an elevation of the seed-bed, thus demonstrating its effectiveness. The most important outcome of the application of RSM is a set of predictive equations and in particular the quantification of the presence of the raised seed-beds in term of increment of weight per cm of elevation (3.70 g cm^{-1}) referred to the indicated transplanting density and soil characteristics.

By a productive-economical point of view, on the whole, raised seed-beds had a global positive effect quantified also on the estimated marketable yields for the period of observation, with significant experimental increases spanning from +13.9% (2011) to +30.6% (2010) on the trials without any raised seed-bed (excluding year 2009). The increases of the net incomes have similar percentages, from +13.2% to 29.7%, calculated by considering the additional costs arising from the creation of seed-beds and the higher revenues due to the increased production. Therefore, on the basis of the illustrated evidences, it is possible to affirm that radicchio, a crop with high incomes, has still development margins and deserves greater attention by the whole production chain. The tests illustrated here have shown that the production of radicchio, and probably of other cultivated chicory varieties, can take an economical advantage from the use of raised seed-beds and, therefore, this system is preferable to the traditional cultivation practice. Hence, bed-former machines, still rarely used because of their price, deserve a greater interest by the farmers, since the higher quantity of harvested crop can quickly cover the purchase cost of this machinery.

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