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Long-term comparison among different soil tillage systems and weed control methods on almond tree growing in southern Italy

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SUMMARY – The research was carried out from 1988 to 2000 in the experimental plot of the almond germplasm field of the Istituto Sperimentale Agronomico of Bari (Southern Italy), under dry farming conditions. The objective of this research was to study the almond tree (cv. 'Filippo Ceo') submitted to different soil tillage systems (conventional, minimum and no-tillage) and different weed control methods (chemical at pre-emergence, weed covering with desiccant treatment and weed covering with mechanical cutting) in a semiarid Mediterranean environment. Minimum tillage was combined with legume green manure. In the case of no-tillage with controlled weed covering and a single chemical treatment or cutting, the biomass was left on the surface for mulching. The no-tillage treatment with chemical weed control at pre-emergence showed higher kernel yield and trunk growth. The highest trunk growth values were observed in the minimum and conventional tillage treatment, with yield values slightly lower than the previous treatment. The lowest yield and growth values of almond trees were found in the no-tillage treatment with controlled weed covering with mechanical cutting.

Key words: Almond, soil tillage, weed control, broad bean green manure, Southern Italy.

RESUME – *"Comparaison à long terme entre différents systèmes de travail du sol et méthodes de contrôle de l'enherbement dans une plantation d'amandiers du Sud de l'Italie". La recherche a été conduite en 1988 et 2000, sur la parcelle expérimentale du champ de ressources génétiques de l'amandier de l'Istituto Sperimentale Agronomico de Bari (Italie du Sud), cultivé en sec. Cette recherche a eu pour objectif d'étudier l'amandier (cv. 'Filippo Ceo') soumis à trois différents types de travail du sol (conventionnel, minimum et jachère) et différentes méthodes de contrôle de l'enherbement naturel (avec un traitement chimique de pré-émergence, avec un traitement desséchant ou avec coupe mécanique) dans un environnement méditerranéen semi-aride. Le travail minimum du sol a été combiné avec l'apport d'engrais vert de cultures légumineuses. Les traitements de jachère avec le désherbage chimique de pré-émergence ont montré un rendement en fruits et une croissance du tronc plus élevés. Dans les traitements de culture minimum et conventionnelle on a observé les valeurs de croissance du tronc les plus élevées et des rendements légèrement inférieurs au traitement précédent. Les valeurs les plus faibles en termes de rendement et de croissance ont été observées dans la jachère avec l'engazonnement naturel contrôlé avec coupe mécanique.*

Mots-clés : *Amandier, travail du sol, contrôle de l'enherbement naturel, apport d'engrais vert de légumineuses, Italie du Sud.*

Introduction

To make almond growing more competitive in the Mediterranean region, it is necessary not only to choose the cultivars carefully, but also to revise the agronomic techniques on the basis of the recent knowledge.

Soil tillage and use of chemicals products in agriculture are the techniques mostly involved in the highly innovative process that took place in the last century (Loreti and Pisani, 1986; Convertini *et al.*, 1997; Castrignanò *et al.*, 2002). Although soil tillage enables weed control, manure ploughing in and increases water infiltration rate, never the less it induces an increase in costs and deterioration of some physical soil properties, causing reduction in porosity and gaseous exchange. The tendency nowadays is towards reduction of tillage, both in depth and in number of interventions or towards no-tillage. A parallel issue is weed control and its interaction with the other site specific cropping techniques**.** Weed control may entail the use of chemical weed-killers, a practice that should be properly calibrated to prevent crop damage, groundwater pollution, accumulation of active ingredients'

residues in the soil (especially if chemical inputs are frequently applied), selection of resistant weeds and negative impacts on microflora. The alternative to chemical weed control is weed covering, which has received increasing attention over the last few years. Extensive research has actually demonstrated that the residues of green biomass, resulting from weed covering, supply the soil with organic matter and mineral nutrients (Haynes and Goh, 1980; Potter *et al.*, 1998; Lal, 1997; Chan *et al.*, 2002), improve the state of aggregation and reduce the detrimental effects of runoff, notably in sloping lands (Chan *et al.*, 1992; Mickelson *et al.*, 2001). The green biomass can also be applied by green manuring of legumes, combined with minimum tillage, a practise that had been nearly abandoned after the development of chemical fertilisers; nowadays, to minimise the use of the latter there is a renewed interest towards this technique, which is an alternative method to improve soil fertility (Baldock *et al.*, 1981, Hossain *et al.*, 1995, Nuti *et al.*, 1989; Mastrorilli *et al.* 1997; De Giorgio *et al.*, 1999).

Within its varietal collection of dry-grown almond tree, established between 1967 and 1968, the Istituto Sperimentale Agronomico of Bari (Southern Italy) has undertaken a research to compare soil tillage systems with different weed control methods by testing the long-term effects of the techniques. The research is at its 28th year, and the same treatments are repeated every year. Several notes have been published, describing both the agronomic results of the 12 first years and the soil chemical properties after 24 years of experimental treatments (De Giorgio *et al.,* 1999). The present note is about the agronomic results of the thirteen-year period 1988 to 2000.

Materials and methods

The experimental field is being run in the plot of agronomic trials of the almond tree germplasm located in Bitetto (close to Bari) in Southern Italy, at 126 m a.s.l. with geographical co-ordinates: 41° 02' 30'' lat. North and 4° 18' 20'' long. East. The test area is historically suitable for almond growing, and it has originated, by natural selection, several cultivars of great interest. The almond tree collection includes 205 cultivars (89 Italian origin, 73 foreign origin and 73 new selections). The soil is clay textured, classified as Lithic Ruptic - Inceptic Heploxeralf (USDA classification, Soil Survey Staff, 1999). The sub-soil is mostly composed by fissured rock that enables the almond rooting system to explore the deep layers. The climate is classified as “accentuated thermo Mediterranean” following the classification of Unesco-FAO Maps and is characterised by hot and dry summers and moderately rainy winters. The period from late winter to early spring is often subjected to late frosts that coincide with almond flowering. The trial period was characterised by an annual mean rainfall of 382 mm (Fig. 1), of which 5 years (1989, '90, '91, '92, '97) with values below 300 mm. The highest rainfall was recorded in 1995 with 668.8 mm, whereas the lowest one was observed in 1991 with 212.63 mm.

The research was undertaken in 1976 and has been going on with the same treatments, which are repeated every year so as to test their long-term effects. This paper presents the agronomic results of the 1988 to 2000 period. A randomised block experimental design with 5 replicates was adopted in the field, with 147 m^2 elementary plots of 3 almond plants (cv. 'Filippo Ceo') of the same age (7x7 m spacing). The comparison involves three soil tillage systems (conventional, minimum and no-tillage) and three weeds control methods (pre-emergence weeds control, desiccant and mechanical cutting), with the following treatment combinations:

(A) No-tillage and chemical weeds control (pre-emergence);

(B) No-tillage and chemical drying with mulching effect on weeds;

(C) No-tillage and weeds cutting with green mulching effect;

(D) Minimum tillage with broad bean (*Vicia Faba,* L*. minor* Beck.) green manuring;

(E) Conventional soil tillage by plough and harrow.

The active substances and doses used for treatments A and B in different years are shown in Table 1, whereas the dates of the different applications in all treatments are reported in table 1. In treatment A the soil is kept free of weeds by using pre-emergence weed removal in one or more annual applications, depending on the requirements.

According to the availability of commercial formulates, the active substances are alternated so as to prevent both their accumulation in the soil and the natural selection of the weeds resistant to the used chemicals. In treatments B and C, in winter the weeds covering was adopted while in late spring the weeds control was differentiated, respectively by desiccant and mechanical cutting, leaving in both treatments the plant mass on the same plots to create a mulching effect.

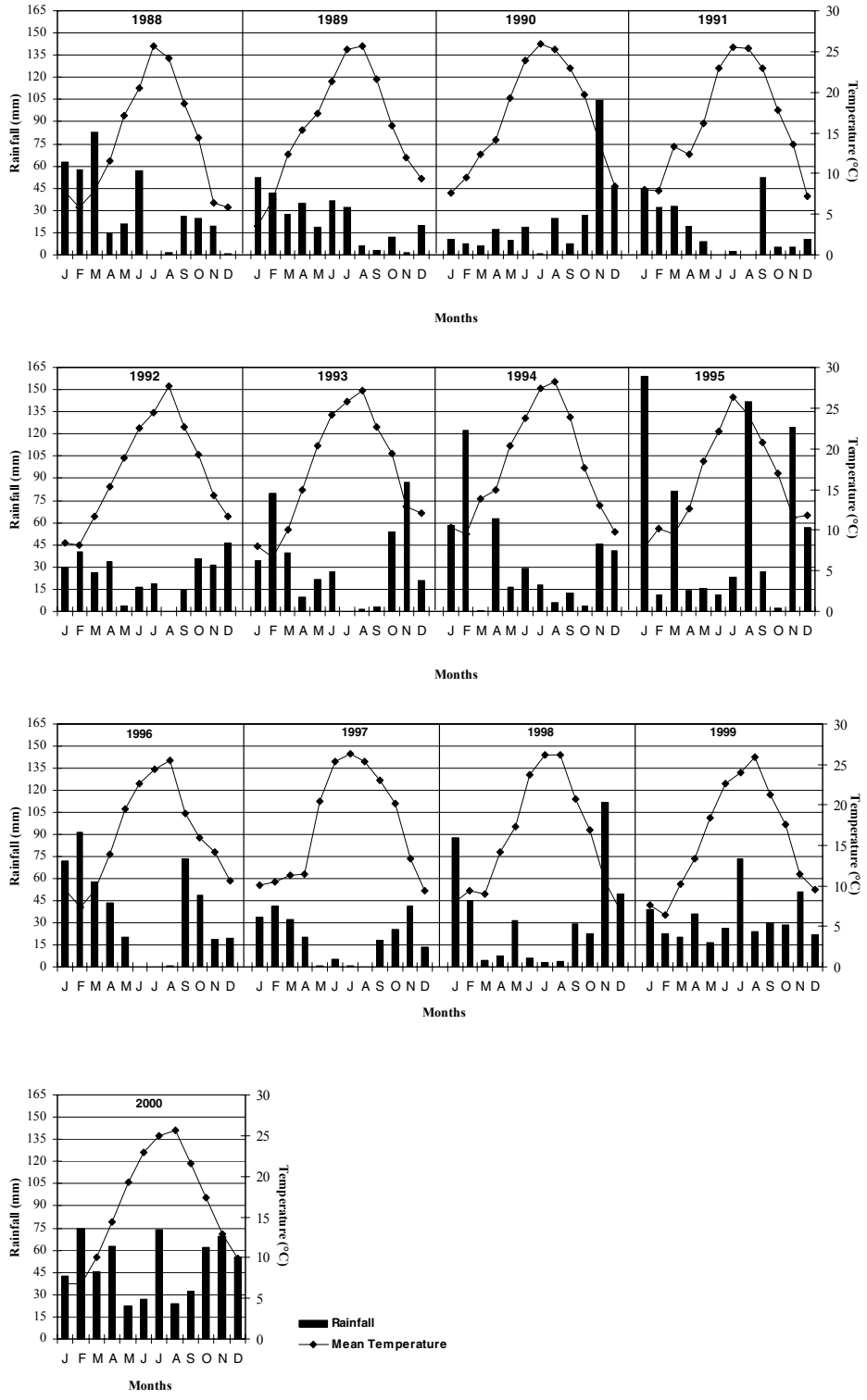

Fig. 1. Trends of monthly rain and mean air temperature of 13 years in the experimental site.

Table 1. Active substance and doses of herbicides in the treatments A and B for each year of the trial

Treatments	Years	Applications (n)	Herbicides	Dosage†
A	1988	1	Bromacile	50 kg/ha
	1989	1	Propyzamide + Simazine	5 kg/ha
	1990	1	Diclhorenil + Tiobezamide	50 kg/ha
	1991	1	Chlorprofam+ Diuron	10 kg/ha
	1992-1998	1	Glifosate + Simazine	12 l/ha
	1999	2	Glifosate	5 l/ha
	2000	1	Glifosate	5 l/ha
	2000	1	Oxadiazon + Glifosate	2.5 l/ha
B	1988 - 2000	1	Paraquat	5 l/ha

†Commercial formula.

In treatment D surface tillage was performed at 10 cm depth by harrow or rotary tiller and in autumn the broad bean has been sown with 200 kg/ha of seed; in springtime green manuring was applied at full flowering. The purpose of broad bean green manuring combined with surface tillage is to enrich the soil with organic matter and with the rhizobium-fixed nitrogen. In conventional tillage several ploughings are performed: deep ploughing (at about 20 cm depth), from late autumn to early winter to favour the water storage in the deep layers and surface ploughing (at 10 cm depth) mostly targeted to remove weeds. This treatment is the control, as it is the standard tillage technique for the test environment.

For the treatments B, C and D, prior to the application of desiccant, the cutting and green manuring, the amount of plant mass was sampled and determined from a surface of 2 m^2 of each elementary plot. A one kg sample was put in the oven at 105°C so as to determine the dry matter yield (%). The weeds of the treatments B and C mainly included *Avena fatua*, L., *Trifolium repens*, L., *Malva silvestris*, L., *Capsella bursa-pastoris*, L., *Calendula arvensis*, L., *Diplotaxis erucoides*, D. C., *Lolium perenne*, L., *Convolvulus arvensis*, L.

Every year, the trunk circumferences were measured at 70 cm above the circumference of ground and the 2 main branches were measured at 15 cm from the point of insertion in the trunks, on each plant of the all tested plots. At harvest the following parameters were measured: the yield per plant, the shelling percentage, the nut and kernel weight, the % of twin kernels. Statistical analysis was made by using the SAS software package (SAS Institute, 2003).

Results and discussion

The applications of the dry matter left on the surface in the treatments no-tillage and controlled weeds covering with a single application of desiccant (B) or with cutting (C), despite an annual variability in both treatments, were similar (Table 2), with values of 2.57 and 2.27 t/ha (average of the thirteen-year period), respectively. In minimum tillage with broad bean green manuring the mean application was 4.28 t/ha, nearly the double as compared to the 2 weeds-covered treatments. In this treatment too, an annual variability was found, due to both the climate pattern and the different emergence degree observed in different years.

The mean production of on almond tree over the thirteen-year period was 3.79 kg of kernel per plant (Table 3)**,** with a maximum value of 6.04 kg in 1992 and a minimum one of 1.96 in 1991.

The latter year was characterised by high temperatures in January that stimulated the early flowering of the almond, and by seven days in February with the minimum temperature below 0°C, which damaged almond flowers and fruits at the start of their formation. The general yield level through the whole trial period was featured by 6 years (1989, '92, '94, '95, '97 and 2000), with a yield ranging between 4 and 6 kg of kernels per plant, and by lower values in the remaining years. The mean shelling percentage was 34.36%, with fluctuations between 37.97% in '94 and 31.04% in '93.

Table 2. Dry matter (t/ha) of weeds and broad been for each treatments in trial period (1988-2000)

Years	Treatments		
	B	C	D
1988	3.57	2.74	6.10
1989	0.85	1.39	3.80
1990	0.97	0.45	3.80
1991	2.47	2.63	5.06
1992	2.05	1.33	6.87
1993	2.20	1.85	3.28
1994	2.49	2.27	4.28
1995	3.68	1.89	5.56
1996	2.54	2.31	4.31
1997	1.64	2.72	4.34
1998	1.76	2.17	1.81
1999	5.74	4.42	2.69
2000	3.48	3.28	3.82
Mean	2.57	2.27	4.28

B = no-tillage with chemical drying of weeds.
C = no-tillage with weeds cutting.
D = minimum tillage with green manure.

Table 3. Effects of the years on the yield and carpological characteristics of the almond tree (cv. 'Filippo Ceo') in the trial period (1988 - 2000)

Years	Yield (kg/tree)	Shelling kernel (%)	Kernel weight (g)	Twin kernels (%)
1988	2.76 c	35.70 cd	1.52 d	28.64 c
1989	5.11 ab	35.71 bc	1.19 g	28.67 c
1990	2.41 c	36.69 ab	1.07 h	26.88 c
1991	1.96 c	32.95 de	1.07 h	17.17 d
1992	6.04 a	33.32 de	1.42 de	28.16 c
1993	2.79 c	31.04 e	1.71 c	46.88 a
1994	5.57 a	37.97 a	1.43 de	27.52 c
1995	5.12 ab	33.99 cd	1.42 de	26.24 c
1996	2.96 c	33.38 cde	1.30 f	24.16 cd
1997	4.35 b	33.00 de	0.92 i	21.84 cd
1998	2.58 c	35.48 bc	1.60 ef	20.38 cd
1999	2.55 c	37.07 ab	2.14 a	43.68 ab
2000	5.09 a	32.39 de	1.00 hi	38.67 b
Mean	3.79	34.51	1.41	29.15

In each column the values followed by different letters are significantly different at $P \leq 0.05$ (SNK test).

The mean kernel weight was 1.41 g, with a minimum value of 0.92 g in '97. This year was characterised by the complete lack of rainfall from May to July, with the maximum temperatures in June and July nearly always above 30°C and with peaks even close to 40°C. These adverse climatic conditions affected the fruit growth negatively with formation of stunted kernels.

The highest kernel weight (2.14 g) was observed in '99, when there was a rain event of 75 mm in July that favoured kernel filling. The mean value of the twin kernels was 29.15%, which was influenced by the high incidence that is above 40% observed in two years 1993 and 1999 and 38% in 2000, as compared to 25% of the remaining years. Further studies are being conducted to identify the factors that induce in some years, that usually coincide with late flowering, an increased incidence of twin kernels far above the mean value of the cultivar.

Among the compared treatments (Table 4) no-tillage with pre-emergence weeds control showed the highest kernel yield, whereas the lowest one was found in the no-tillage with weeds covering and mechanical cutting of weeds.

Table 4. Effects of the treatments on the yield and carpological characteristics of the almond tree (cv. Filippo Ceo) in the trial period (1988 - 2000)

Treatments	Yield (kg/tree)	Shelling kernel (%)	Kernel weight (g)	Twin kernels (%)
A	4.86 a	34.82 a	1.50 a	30.21 a
B	4.05 b	34.78 a	1.39 b	27.25 a
C	2.72 c	33.55 b	1.34 b	29.21 a
D	3.56 b	34.92 a	1.40 b	30.35 a
E	3.77 b	34.47 a	1.41 b	28.95 a
Mean	3.79	34.51	1.41	28.96

In each column the values followed by different letters are significantly different at $P \leq 0.05$ (SNK test).

These results show that in the test environment, characterised by a low rainfall from spring to summer, the competition of both spontaneous weeds growth (treatments B and C) and cultivated plants (broad bean treatment D) has a detrimental impact on almond production. Water is a limiting factor that also jeopardises conventional tillage, which involves turning of the soil during the different ploughings, thus favouring water evaporation. Moreover, when tillage is performed the environmental conditions do not always allow timely interventions, allowing weeds, albeit for a short period, to compete with the crop. The almond tree grown with minimum tillage and broad bean green manuring cannot benefit from organic matter application and nitrogen fixation, maybe because organic matter and nitrogen are mostly concentrated in the top layers, which are less explored by the rooting system that, in dry farming, tends to grow deeper and deeper to find water and nutrients.

The weeds-covered no-tillage treatment with cutting is the unique with a significantly lower shelling percentage as compared to the other treatments, which do not differ among them. The absence of competitiveness with herbaceous vegetation in the no-tillage treatment with pre-emergence weeds control, favoured a better fruit development with the highest kernel weight. The treatments did not influence the percentage of twin kernels.

As to the trunk circumference growth between 1988 and 2000 (Table 5) the only difference observed was the lowest growth in the no-tillage with weeds cutting, with significant differences as compared to the conventional and the minimum tillage systems with broad bean green manuring. Also as to branch growth, treatment C showed the lowest values but non-significant differences.

Further soil analyses are being conducted, both in chemical and microbiological properties, with a view to identify the causes that led the no-tillage treatment with mechanical weeds control to show the lowest values in the different observed parameters. This might presumably be due to the greater difficulty in the exchange of telluric air as a result of the plant residues, which accumulate on the surface, thus creating a compact organic layer. That may cause a barrier effect from late spring to summer, a period of luxuriant vegetative growth for the almond. This assumption will be checked by the on-going studies.

Table 5. Increases of trunks and branches circumference of almond tree in the trial period (1988 - 2000)

Treatments	Circumference differences	
	Trunks (cm)	Branches (cm)
A	9.69 ab	7.88 a
B	9.83 ab	8.87 a
C	8.60 b	7.60 a
D	10.33 a	8.63 a
E	10.50 a	7.95 a
Mean	9.79	8.19

In each column the values followed by different letters are significantly different at P≤0.05 - LSD=1.58 for trunks and 1.59 for branches.

Conclusions

The thirteen-year period of different soil tillage and weed control methods, was characterised by a great annual variability in the different measured parameters, mainly due to the different climate patterns. The dry matter input was nearly double in the broad bean green manuring as compared to the two weed-covered treatments treated with desiccant or cut only once a year in springtime.

Among the five compared techniques being, the no-tillage with pre-emergence chemical application gave the highest kernel yield per plant and the highest kernel weight. In the no-tillage with weeds cutting, the lowest values were observed both in yield and shelling percentage. The other soil tillage systems were at an intermediate level and were quite similar. The highest growth trunks and branches values were observed in minimum and conventional tillage, particularly in the no-tillage with weeds cutting that showed the minimum value. In short, in the trial environment characterised by low rainfall, the treatments involving the presence of both spontaneous and cultivated plant biomass, induced competition with the almond tree for the use of the water resources and nutrients available in the soil. Therefore, on the basis of these results it is recommended to use no-tillage with one or more chemical treatments at pre-emergence so as to ensure the complete absence of weeds.

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