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Energy savings in plant production

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Abstract. At the moment energy costs in agriculture are relatively low compared to other costs. In 2010 energy costs were 10% of the total agricultural costs in Finland. However, energy costs are expected to grow. The EU has made a directive on Energy End-Use Efficiency and Energy Services, which claims that agriculture must save 9% of their average energy consumption of the period 2001–2005.
The highest energy consumptions in plant production originate from agro-chemicals (fertilizers, lime and pesticides). However, regarding energy statistics, energy consumption for agro-chemicals is allocated to the industrial sector. Chemicals are for this reason seen as indirect energy in agriculture.
Direct energy input in agriculture consists of fuels and electricity. The most dominating direct energy input in plant production is diesel and heating oil. Energy consumption can be easily decreased in plant production by some 10–30%. For instance, 10–20% of energy can be saved in grain drying by heat insulation. In machine operations the dominating factor in energy consumption is the driver. With properly implemented maintenance and adjustment and efficient driving habits, 10–30% savings can be achieved

Keywords: energy, agriculture, plant production.

Introduction

The share of energy costs have increased during recent years. Fig. 1 shows the direct energy costs percentage share from the year 2000 to the preliminary figure of the year 2011 (Maatalouden kokonaislaskenta). The share of direct energy costs have doubled during the 11 year period. Because fossil energy resources are limited and at the same time consumption has increased, the fossil energy costs will be even higher in future. The fuel consumption in agriculture is about 300 million liters in Finland and in Estonia 100 million liters annually (Tietohaarukka 2011, Statistics Estonia).

EU Energy Service Directive (EU 2006/32/EC) has stated that member states should save 9% of energy by the year 2016 compared to the years 2001–2005. The energy saving is calculated from the total energy end use not including shipping, aviation and industry, which are under emission trading. The energy consumption in Finnish agriculture has been estimated to be 12 TWh (Maatilojen energiaohjelman vuosiraportti, 2010). This means that the saving should be about 1 TWh, which is about 100 million litres of diesel oil.

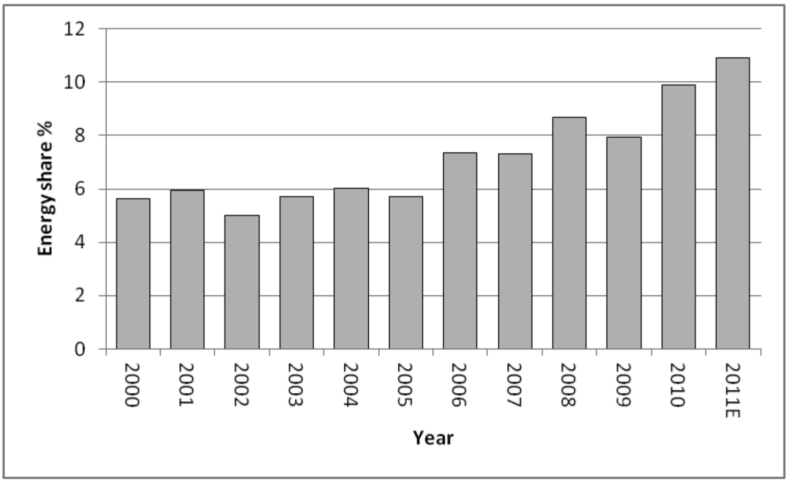

Fig. 1. Share of direct energy costs from total costs of agriculture in Finland (2011E = prediction for year 2011).

University of Helsinki department of Agricultural Sciences together with MTT Agrifood Research Finland, Estonian University of Life Sciences, Seinäjoki University of Applied Sciences and Jyväskylä University of Applied Sciences, have two EU funded energy projects ongoing, and this article is a review on the findings of these projects.

Fig. 2 shows a typical direct energy use in conventional barley production. The main direct energy consumption in crop production accounts for tillage work, combine harvesting and grain drying. Transport energy consumption depends on the field plot structure of the farms. If the plots are far away from the farm centre, then transport fuel consumption is high. If indirect energy consumption is also included, then production intensity usually determines the consumption of mineral fertilizer and fuel. Studies have shown production and utilization of mineral fertilizers account for up to a third and to more than half of the total energy used in agricultural production in developed countries (Hülsbergen et al., 2001; Rathke et al., 2002; Baali et al., 2005; Mikkola and Ahokas, 2009). Leguminous and catch crops in the crop rotation enable some savings from mineral nitrogen, which is the most costly part of mineral fertilizers, but the effect depends strongly on the weather conditions.

However, in field operations the driver plays the most influential part. He decides how to adjust the implement, which gear to use during the work and how he drives the tractor or self propelled working machine.

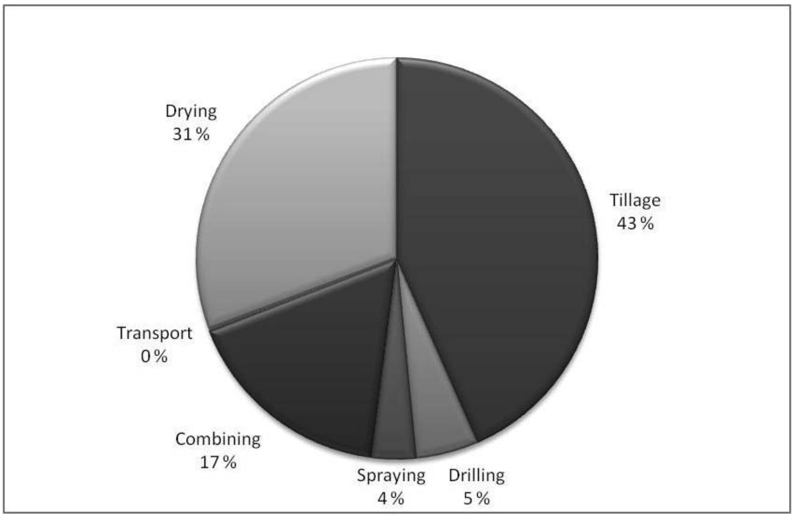

Fig. 2. Direct energy use in conventional barley production, grain moisture content 19% (Mikkola & Ahokas, 2009).

Fig. 3 shows a typical diesel engine performance curves. The minimum specific fuel consumption is 204 g kWh^{-1}. In order to utilize this, the engine power must be about 90% of the nominal power and speed about 80% of nominal speed. When the power need is low, there can be quite a difference in consumption depending on how the driver uses the tractor. For instance, if 20% of the nominal power is needed, the consumption can be between 230–400 g kWh^{-1}. This is due to the fact that at high engine speed and low power output the fuel power is lost in engine friction and engine gas exchange.

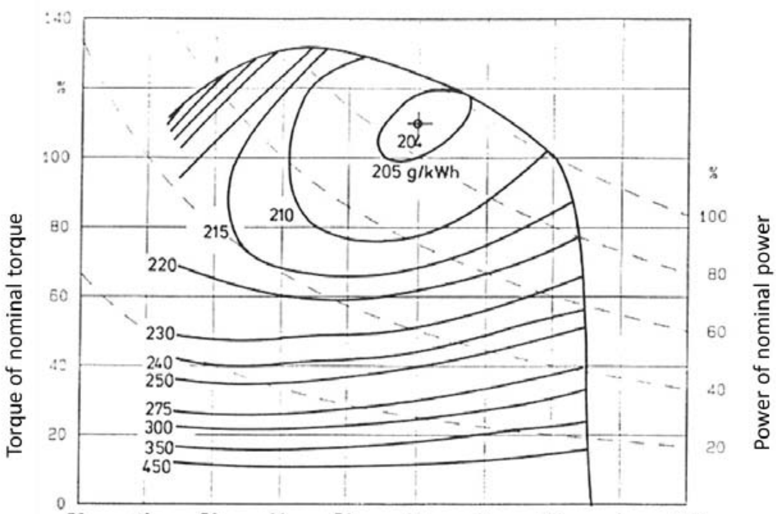

Fig. 3. Engine performance curves (OECD 1992).

For low fuel consumption the old advice 'shift up, throttle down' also works for tractor diesel engines. Fig. 4 shows an example of a test done during harrowing (Ahokas & Mikkola, 1986). The reference in this picture is 5^{th} gear and full engine speed. When 6^{th} gear and reduced engine speed was used, the work rate and tractor speed was about the same as in 5^{th} gear, but fuel consumption was some 30% lower. It is up to the driver how he drives the tractor. With proper consumption meters, which show the consumption in l ha^{-1}, the driver could see the result easily. Consumption figures in l ha^{-1}do not take into account the work rate. The work rate and consumption in l ha^{-1}should be combined to show l ha^{-1} figures. At the moment more and more tractors and implements are equipped with on board computers and ISOBUS (ISO 11783) communication protocol. In these tractors with stepless CVT-transmission it is possible to program the tractor to work in an energy efficient way.

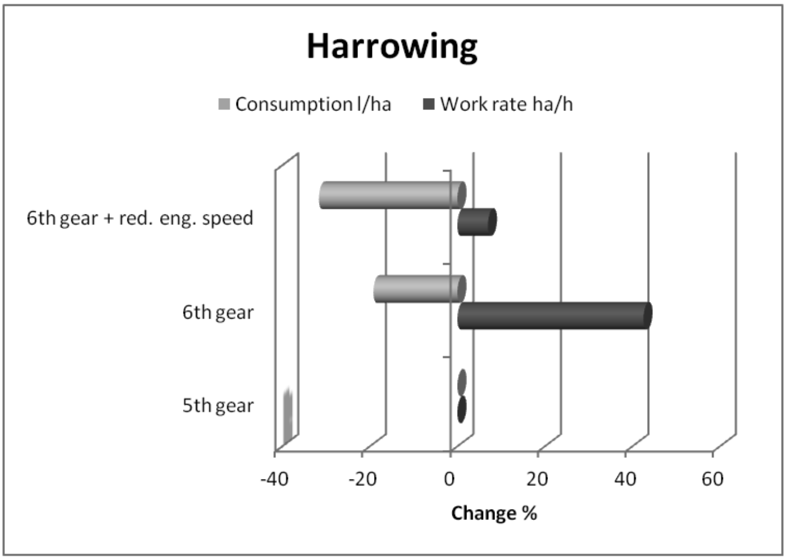

Fig. 4. Fuel consumption l ha^{-1} and work rate ha h^{-1} during harrowing (Ahokas & Mikkola, 1986).

Fig. 5 shows the effect of ploughing depth. When ploughing depth is less than 20 cm, consumption is 12–13 l ha^{-1}. With 27 cm working depth the consumption is about 18 l ha^{-1}, an increase of about 50% (Ahokas & Mikkola, 1986).

In ploughing the plough adjustment also has an effect on fuel consumption. Ahokas & Mikkola (1986) found that plough inclination towards the ploughed soil increased friction forces so that the total draft increased some 50%.

During the year 2000 the global cereal production depended on mineral fertilizers by 64% (Roostalu, 2008). In Estonia the transitional period induced changes in fertilisation intensities. In 1992 the total available organic fertilizers accounted for up to 7.0 mill t, while in 2010 the amount was 2.6 mill t. The use of mineral fertilizers decreased until the turn of the century, and showed an increasing trend thereafter. The amount of active substance of $N/P_2O_5/K_2O$ per fertilized area in 2000 was 82 kg ha^{-1}

and increased up to 126 kg ha^{-1} by 2010. National level analyses show negative plant nutrient balance of arable soils in Estonia (Astover, 2007).

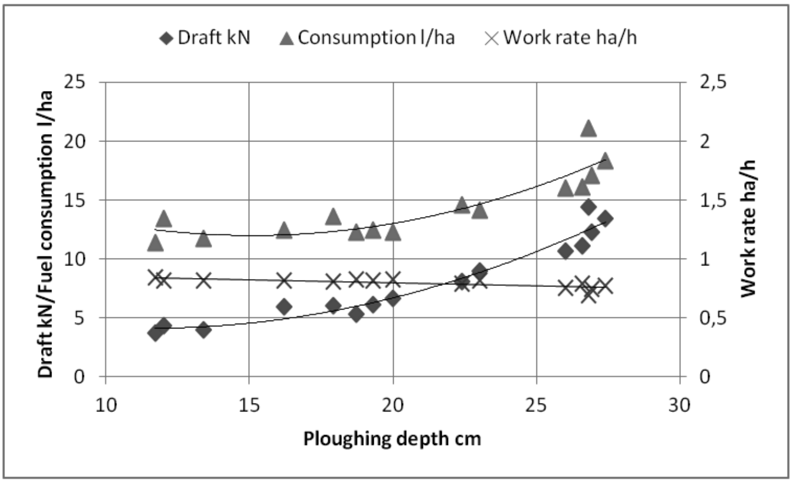

Fig. 5. Effect of ploughing depth on work rate, draft and fuel consumption (Ahokas & Mikkola, 1986).

In Finland the fertilizer use has decreased since 1990 when it was at its highest. In 1995 the terms for environmental subsidies set limits to fertilizer use. The maximum nitrogen and phosphorus amounts depend on the plant, soil type and region of the country. Subsidies are paid only for those farms which use fertilizers according to the regulations. In 1990, 110 kg nitrogen was used for one hectare and in 2008/2009 the corresponding figure was 59.4 kg ha^{-1}. The use of phosphorus has decreased during the same time from 30 kg ha^{-1} to 4.7 kg ha^{-1}. Potassium use was 14.4 kg ha^{-1} during 2008/2009 When nitrogen, phosphosurs and potassium are added together, 78.5 kg ha^{-1} was used in 2008/2009 overall. (Työryhmämuistio MMM 2009:1; Maatilatilastollinen vuosikirja 2010).

Materials and methods

During the ENPOS project, tractor and grain drying energy consumptions has been measured on several Estonian and Finnish farms. The tractor fuel consumption was measured by bookkeeping and by simple data logging systems (Jokiniemi et al., 2012). These figures are compared to figures measured on other farms and found in literature.

Grain drying measurements were also done on several farms in Finland and Estonia. The energy consumption was measured with the method described by Jokiniemi et al (2011). A comparative study was also made with two identical grain dryers with and without heat insulation.

Fertilizer use was studied mainly in Estonia. The results are based on the trials carried out during 2004 to 2010 growing seasons at the Department of Field Crop Husbandry in Estonian University of Life Sciences (EMU), Institute of Agricultural and Environmental Sciences (58°23′N, 26°44′E). The soil type of the experiment area was sandy loam Stagnic Luvisol by WRB 1998 classification with low organic carbon content (1.1–1.2%), and pH_{KCl} (5.9).

The studied green manure crops were: a) legume pure sowings (i) red clover (*Trifolium pratense),* (ii) lucerne *(Medicago sativa),* (iii) hybrid lucerne *(Medicago media)*, (iv) bird's-foot trefoil (*Lotus corniculatus),* (v) pea (*Pisum sativum*) (vi) melilotus (*Melilotus albus*); b) spring barely with undersowings of (i) red clover, (ii) lucerne, (iii) hybrid lucerne, (iv) bird's-foot trefoil, (v) pea, (vi) westerwold ryegrass *(Lolium multiflorum westerwoldicum Wittm)* (vii) melilotus (*Melilotus albus*); c) spring barley with dairy manure applied in autumn (60 Mg ha^{-1}); d) spring barley with mineral fertiliser rates (i) N_0 – the control variant, (ii) N_{50}, (iii) N_{100}. The effect of legumes was studied on oats, spring- and winter wheat during the first succeeding year and on barley during the second succeeding year.

Results and discussion

Table 1 shows the results of fuel consumptions on farms. When compared to the figures given by Mikkola & Ahokas (2009), these figures are of the same magnitude but in ploughing and combine harvesting the figures differ considerably. Mikkola & Ahokas (2009) took the figures mainly from central European measurements. Different circumstances and yield levels is one reason for the differences in figures. Soil conditions and driving habits also have an effect on this. The figures show that there can be quite a difference in consumption figures and figures from different circumstances are not always correct.

From table 1 we can also see that the production arrangement has effect on consumption. When hay making, baling and loader wagon are compared, the consumptions are quite different. By choosing the right production system and machines, energy can be saved during the work.

Table 1. Measured fuel consumptions compared to fuel consumption found in literature (Mikkola & Ahokas, 2009)

Type of work	**Measured fuel consumption** l ha^{-1}	**Fuel consumption in literature**[1] l ha^{-1}
Harrowing	7–10	5.4
Sowing	5–8	3.7–7.6
Combine harvesting	9–11	15.1
Ploughing	16	25.1
Manure spreading*	4	-
Cutting grass	4–5	6.0
Baling	5	–
Loader wagon operation	15	–

[1]Mikkola & Ahokas, 2009

Grain drying can consume in worst cases as much energy as is used in the field operations altogether. Dryers are used for only a few weeks during the year and for this reason the investment must be kept low. However, grain dryer efficiency can be increased with low investments. Normally the dryer is not heat insulated and the pipes and dryer intake surfaces have surface temperatures of 50–60°C, which cause some 300–500 w $(m^2)^{-1}$ heat loss. Two identical dryers' energy consumption was measured during normal drying operation. One of these was un-insulated and the other one had heat insulation on the inlet ducts. With insulation the energy consumption could be decreased some 10–30%. Fig. 6 shows an example of grain dryer insulation.

Fig 6. Example of grain dryer insulation.

High drying temperature improves drying energy efficiency. In fig. 7 a theoretical calculation is shown of this. In batch dryers when the outlet temperature increases, high drying temperature gives better efficiency, especially at the end of drying. The limits for drying temperature depend on the use of grain. For seed production a low temperature is needed to insure germination, but for feed production high temperatures do not spoil the nutritional value.

Grain dryer efficiencies could be improved further with more advanced process control and with heat recovery systems. The energy saving could be more than 50%, but at the moment it is not economical (Ahokas & Koivisto, 1983). Renewable fuel can also be used in grain dryers. This does not improve energy efficiency, but reduces plant production dependence on fossil energy.

Organic fertilizers play a central role in sustaining soil fertility and crop productivity. In specialized crop farms where the use of animal manure is limited, green manures provide the most effective way to improve the N supply for succeeding crops (Thorup-Kristensen et al., 2003). Studies in Estonian pedo-climatic conditions with pure sowing leguminous green-manure crops have shown high total biomass N content (70–274 kg ha^{-1}) depending on the species, weather and the year of harvesting (Talgre et al., 2009).

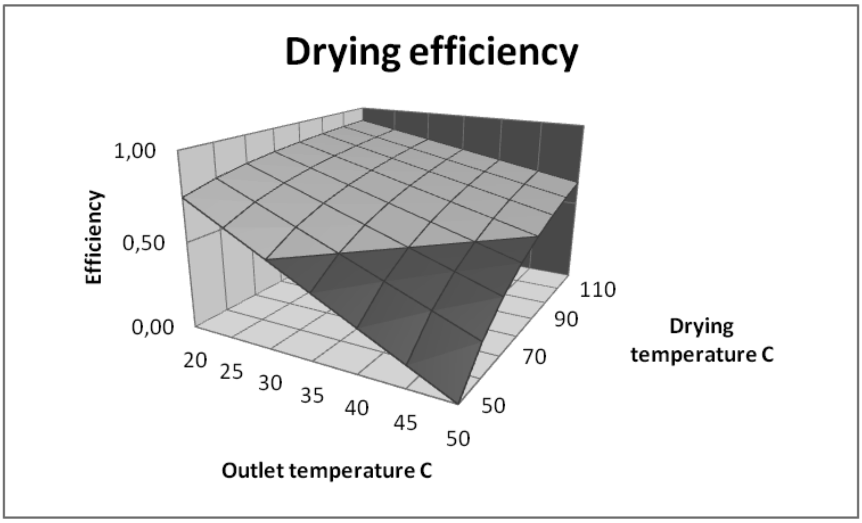

Fig. 7. Effect of drying temperature on drying efficiency.

The effect of nitrogen applied into soil by leguminous plants was assessed by the yield of the succeeding crop compared to mineral nitrogen norm 100 kg ha^{-1}. Under-sowings with barley provides a significant increase in the N supply for the succeeding crop without any yield loss of the main product yield compared to the unfertilized variant (N0). If 100 kg of nitrogen is applied to the soil by leguminous plants, the first year after effect gives a yield increase of 43%, second and third year after effect accordingly 34 and 10% compared to unfertilized plots. Twice higher nitrogen amount (200 kg ha^{-1}) applied to the soil by leguminous crops, which is realistic when pure sowings are used, gives an additional yield on the first, second and third year accordingly of 86%, 68% and 20%. The first year yield increase is comparable with mineral nitrogen norm 100 kg ha^{-1}. The effect of nitrogen applied into the soil with green manure on succeeding crops depends on the C/N ratio of the applied organic matter and the time of application. Green manure with high nitrogen content should be ploughed into the soil in spring, thereby decreasing the leaching potential of nitrogen and environmental pollution. The results of the trials in Estonia attest with spring ploughing, as the efficiency of green manure is up to 600 kg ha^{-1} greater on the yield of cereals grown as succeeding crops than with the autumn ploughing-in of green manure (Talgre et al., 2009). By substituting mineral N by legumes the energy saving during first year succeeding crop can even be 100% depending on the crop and year. The second year after effect is lower (35%), but considerable. In plant production leguminous crops are usually grown as under-sowings to the main crops. It is economically low cost demanding. Energy costs are done for seed materials and sowing operation which can be considered about 0.3 GJ ha^{-1}. Preparation of the field for pure sowings is about 1.4 GJ ha^{-1}. Total energy costs in Enpos project plant production case farms in Estonia were about 8 GJ ha^{-1} and fertilisation accounts ca 60% of total costs (Rossner et al., 2012). The costs for seedbed preparation and sowing of leguminous plants were divided by two years as having the main effect on succeeding crops. The complementary mineral nitrogen amounts by under-sown legumes (table 2) can save energy 2–4 GJ ha^{-1} (25–60%) of total costs depending on the year and succeeding crop. The effect of under-sowings on second year succeeding crop was 0.6–2.0 GJ ha^{-1} (10–25%) of total costs. Effect of pure sowings on the first and second year succeeding crop can give savings accordingly of 3–5.3 (30–65%) GJ ha^{-1} and 1–2.2 GJ ha^{-1} (12–27%).

Table 2. Complementary mineral nitrogen amounts for succeeding crops achieved by two leguminous crops as pure and under sowings, GJ ha^{-1}

Precrop	Complementary mineral N amount for I year succeeding crop, (GJ ha^{-1})		
	Oats 2006	Spring-wheat 2007	Winter wheat 2008
Barley+red clover	4.2	2.2	5.1
Barley+melilotus	–	2.7	4.1
Red clover	5.7	4.3	–
Melilotus	–	6.6	–
	Complementary mineral N amount for II year succeeding crop, GJ ha^{-1}		
	Barley 2007	Barley 2008	Barley 2009
Barley+red clover	1.7	0.7	2.1
Barley+melilotus	–	1.0	1.2
Red clover	2.9	1.7	–
Melilotus	–	2.1	–

On a farm scale the energy savings depends on crop rotation and the proportion of legumes in it and their growing time. It should also be kept in mind that weather conditions affect the green manure biomass yield to a large extent.

Conclusion

In field work the easiest and most cost effective way to save fuel is by educating the drivers. The driver affects fuel consumption in the following ways:

- By choosing the optimum engine load (gear/engine speed)
- By choosing the right working speed
- By choosing the working depth
- By adjusting the machine correctly
- By maintaining the machine correctly
- By choosing the energy effective production methods.

The driver can save energy by 10–30% depending on the driving habits. This saving can be done without any investment in proper education material.

Modern tractors have in many cases on-board computers. It is possible to program the tractors to work energy efficiently, especially with stepless transmissions.

In grain drying alone with simple heat insulation a considerable saving can be achieved (10–30%). Grain drying efficiencies can be further improved with better process control and fossil energy use can easily be changed to renewable use. Grain drying heat insulation is the cheapest way to improve efficiency, the payback time is around three to five years depending on fuel price and insulation costs.

Fertilizer use and indirect energy consumption can be reduced by using leguminous crops. In addition these play a central role in sustaining soil fertility and crop productivity. Under-sowings of leguminous crops (red clover and melilotus) can save energy on first and second year succeeding crops accordingly of 25–60% and 10–25% of total costs. Energy saving effect of pure sowings was 13–65% and 12–25% respectively. During the first succeeding year leguminous may cover 100% of fertilizers energy costs. However, weather conditions affect the green manure biomass yield to a large extent and for this reason the leguminous plants nutrient binding effect can´t be considered as a guaranteed saving option.

The fuel consumption in agriculture in Estonia and Finland combined is about 400 million litres. A 10% saving, which is quite realistic, means 40 million litres annually. With this fuel amount about 15,000 small houses could be heated annually.

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